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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STREAM POLLUTION BY ACID-IRON WASTES

A REPORT BASED ON INVESTIGATIONS MADE AT SHELBY, OHIO

BY

HERMAN STABLER

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STREAM POLLUTION BY ACID-IRON WASTES.

By HERMAN STABLER.

INTRODUCTION.

Stream pollution by ironworks effluents has always been an important question in countries where the iron industries are prominent. The polluting liquors, commonly known as "acid-iron" liquors, are derived from the "pickling process" common to galvanizing, tin plating, tube and sheet iron treatment, and, in fact, all work in which a clean iron surface for coating or other purpose is required. The clean surface is obtained by immersing the material in a fairly strong solution of hydrochloric or sulphuric acid, which readily removes the surface impurities and at the same time attacks the material itself, dissolving it or uniting with it to form new compounds. As a result of the process the material treated comes from the bath with a surface as clean and bright as if newly polished. By continued use the acid solution becomes gradually weaker, iron chlorides or sulphates being formed, and the whole bath becomes more or less impregnated with impurities, chief among which are practically insoluble iron oxides. Finally the solution becomes too weak for further profitable use and is discarded as waste, technically known as "waste pickle." This waste pickle, it is said, has been bottled and sold as tonics for human consumption, though not with great success. Used in small quantities, however, it is beneficial to both animal and vegetable life. It is not a desirable addition to streams (1) because it produces a reddish discoloration and turbidity, making the stream waters, bed, and banks unsightly; (2) because, by reason of its avidity for oxygen, it robs the waters of their natural supply of this essential gas and thereby, when it is present in comparatively large quantities, causes the death of fish, and (3) because it gives rise to a large quantity of iron in the stream, and thereby impairs the usefulness of the water for domestic and laundry purposes and for certain manufacturing processes.

In many cities waste pickle is discharged into the sewers. Where the quantity of pickle is relatively very small this method of disposal is not objectionable. Too frequently, however, there is enough free acid in the waste liquors to corrode the sewer joints and metal fittings,

and, in case there are sewage purification plants, to interfere seriously with the working of the purification processes.

At Shelby, Ohio, acid-iron wastes have been discharged into a watercourse and also into the sewers of the town, causing conditions which have led to lawsuits and complaints directed to the Ohio State Board of Health. It was determined, therefore, to investigate at this city the factory processes which are accountable for the alleged nuisance and the conditions at the sewage-disposal farm and along the stream. The investigations were performed under a cooperative agreement between the United States Geological Survey and the State Board of Health of Ohio, each bureau participating equally in the expenses involved. All expenses for analytical work and for transportation of samples, together with the traveling expenses and subsistence of the investigators, were borne by the Ohio State Board of Health, so that joint credit should be given to the two bureaus participating in the work.

The pollution at Shelby having extended over a term of years under varying conditions, it was thought advisable to make the investigation cover (1) the history of the pollution and the attendant litigation; (2) the effect of acid-iron liquors upon sewage purification processes; (3) the conditions along the stream, and (4) the disposal of acid-iron wastes without discharge into watercourse or sewerage system.

It is desired to make acknowledgment of assistance received in the investigation from Mr. William F. Sonnanstine, superintendent of the Shelby sewerage system; Messrs. Mansfield and Long, attorneys, and Mr. A. C. Morse, superintendent of the Shelby Steel Tube Company. Mr. M. O. Leighton, chief of division of hydro-economics, U. S. Geological Survey, personally supervised and directed the course of the investigation. In addition to sharing the expense of the investigation the Ohio State Board of Health accorded active cooperation by affording the use of its laboratory to the writer and by making sanitary determinations of the eight samples of sewages listed in the table on page 18, which were made in the laboratory of the Ohio State Board of Health under the direction of Mr. E. G. Horton, bacteriologist and chemist.

HISTORY OF POLLUTION BY ACID-IRON WASTES AT SHELBY, OHIO, AND RESULTING LITIGATION.

The Shelby Steel Tube Company maintains a large plant on the bank of a brook within the city of Shelby. The tube mills were first operated in 1890, since which time the present company and its predecessors have, to a greater or less extent, discharged their liquid wastes into the adjacent brook, which, for convenience, we shall designate Red Brook, no generally recognized local name being applied to it. The flow of Red Brook varies perceptibly with the flow of waste water

from the tube works, but is generally about one-fifth or one-sixth as great as that of Black Fork,[a] into which it discharges in the upper part of Shelby. Black Fork traverses the city from south to north, passing on through an agricultural district, and finally reaching Muskingum River.

Until sometime in 1902 the entire waste of the tube works was discharged into a settling basin, from which it overflowed to Red Brook, giving to it and to Black Fork a red discoloration for miles below. No very vigorous protest against this pollution seems to have been made until October 20, 1902, when petition was filed and suit for $2,500 damages was begun in the court of common pleas of Richland County, Ohio, against the Shelby Steel Tube Company by Isaac Noecker, a farmer having 50 acres of bottom land subject to overflow from Black Fork about 4 miles below the tube works. Previous to this time it was apparently the view of all parties concerned that the tube works, employing a large number of men, was an industry to be fostered; that the stream was the only available means for the disposal of its waste, and that any inconvenience resulting from stream pollution by the works should be borne on account of its general benefit to the community. This is probably the view now taken by the city in allowing the effluent from the tube works to enter its sewerage system, permission for such use of the sewers being taken advantage of by the company in 1902—a direct result, no doubt, of the growing legal complications attending the discharge of the waste liquors into the stream. At the time sewer connection for the tube works was made the overflow from the settling reservoir was conducted to a filtering bed of crushed limestone, from which tile underdrains carried it to the sewer. This arrangement supposedly stopped all pollution of Red Brook, but actually served merely to divert a moiety of the polluting liquors, for infiltration, leakage, and probably overflow from clogged filters still carried to this stream a considerable flow of acid-iron waste. However, it transferred the principal point of pollution to the sewer farm outlet, 3 miles below Shelby, and bettered conditions all along the stream very materially.

In the petition above mentioned, it was claimed that—

> Defendant [the Shelby Steel Tube Company] in operating its said factory pours into said stream great quantities of poisonous matter and offals from said factory, which poison the water in said stream and render it destructive of animal and vegetable life. And said poisonous deposits in said stream, when the water is high, overflow plaintiff's said low lands, thereby poisoning the vegetation and pasture thereon, rendering it unfit for animal food and dangerous to animal life.
>
> Said poisonous matters poured into said stream render the water unfit for domestic use and sicken and poison plaintiff's animals that pasture on said ground when they drink thereof.

[a] Black Fork is a small stream having at this place (Shelby) a watershed of about 40 square miles, and a dry-weather flow of perhaps 1 to 3 cubic feet per second. Eighteenth Ann. Rept. Ohio State Board of Health, 1903.

In the answer of the defendant to the petition, it was claimed—

that if said stream is polluted to such an extent as to be a nuisance and of injury to t plaintiff, that the same is caused by causes other than those alleged in the petition.

The case came to trial in June, 1903. Nearly all witnesses for t plaintiff were farmers owning land along the Black Fork below Shelb With few exceptions these men had instituted or were intending institute similar suits against the company, concerted action havi been determined upon. Each, as he testified, realized that the su cessful outcome of his own suit would be largely dependent upon t winning of this first suit of the series.

The testimony of witnesses for the plaintiff, in brief, was about follows:

1. Previous to the operation of the tube works the Black Fork w satisfactory as a water supply for stock; gave no appearance of pc lution; was the home of numerous healthy fish, and was used as i and boiler supply and for domestic purposes.

2. After the installation of the tube works the stock would n readily drink the water; cows watered from the creek suffered d crease in milk; cattle pastured adjacent to the creek got sick ar some died, removal to a field from the creek effecting the recovery stock. The creek water was sometimes very red and sometimes blu turbid, and had a black ashy sediment; overflow of the stream stunt crops, turned them red, and destroyed grass; stock refused to e pasture which had been overflowed; dead fish were found along tl stream, and few, if any, live fish could be caught, and the value of tl stream as a source of ice and boiler supply was destroyed.

3. Injury to stock was believed to be due to use of creek water pasture that had been overflowed by the creek. In some cases, ho ever, death of stock was certainly due to other causes, as shown l autopsy.

4. Said damage occurs all along the stream from 3 to 12 miles belc tube works.

Witnesses for the defense testified that:

1. No difference in pasturage was noticeable in last twenty-fi years; that they had caught fish or seen others fishing all along t polluted stream, and that no damage to stock or pasture resulted land immediately below entrance of tube works effluent.

2. Damage on stream might have resulted from bursting of an tank.

3. Chemical analyses in January, 1903, of samples taken from R Brook below the tube works and from Black Fork above, 3 mil below and 4 miles below the entrance of Red Brook, showed a lit free acid in Red Brook, but none in Black Fork. The stream 4 mil below showed the presence of the following amounts of solid matt in parts per million: Silica, 11.97; iron and alumina, 8.55; lim

127.99; sulphuric anhydride, 102.60. The expert witness who made these analyses, Prof. Albert W. Smith, of the Case School of Applied Science, Cleveland, Ohio, testified, in part, as follows:

In the process of pickling, an acid is used for the purpose of cleaning the surface of iron. The iron surface is covered with what is called rust, and the acid dissolves rust; it combines with it chemically, and both acid and the rust, as such, are destroyed—they become a new substance. When two things combine chemically a new thing is formed; that is what is meant by chemical action. When acid and iron rust come together, both the acid and rust, as such, are destroyed, and they form a new substance, green vitriol or iron sulphate. That cleans the surface of the iron, and the iron sulphate forms a clear solution with the water that the acid is dissolved in, but the acid and the iron have been destroyed as such.

When this liquid flows into this little stream [Red Brook] it makes it acid, and the little stream contains this sulphate of iron. It is a clear liquor solution, just like sugar in tea. The large brook [Black Fork] contains lime in solution, a clear, transparent liquid, but the lime is there, just the same, in solution. When the lime and the iron sulphate come together they combine chemically and form a new substance. They form sulphate of lime, or land plaster, which is soluble in water, and the same iron rust that was present in the iron; that is, the iron has gone back to the same condition it was in when it was rust on the iron, and as such is not soluble in water. It will not dissolve any more, so it spreads out, a yellowish and brownish rust. The iron rust settles to the bottom of the creek, and hence is separated from the water. There would be no iron in the water, as it settles to the bottom and stays there, just as so much clay or mud would. It settles in the water below, and there is neither acid nor iron.

The iron, after it separates and is precipitated to the bottom, is of a yellow or reddish-yellow color, just like yellow clay, and is very much the same in its chemical properties.

I think it would have the same effect upon plants or animals as so much clay would. This is inert matter, just like clay or mud.

The charge of the court (Robert M. Campbell, trial judge) is of particular interest, voicing as it does the rights of riparian owners and the views of such rights that obtain in Ohio. The prominent points in the charge are as follows:

1. All riparian owners have a right to the use of stream waters in a normal state.

2. Their right to the use of the water is limited to such use as shall not substantially decrease the value of the stream to riparian owners below them.

3. Their right to the water in a normal state is subordinate to a usual and ordinary use of the water by riparian owners above them.

4. Every party contributing to stream pollution is responsible for damage done thereby.

5. Riparian owners injured by stream pollution have a right to compensation for such injury in direct proportion to the loss sustained.

6. The injury sustained may be in the nature of a deprivation of the use of the water for any reasonable purpose or of damage done to property, but must be substantial and not mere inconvenience or occasional annoyances in order to warrant an award for damages.

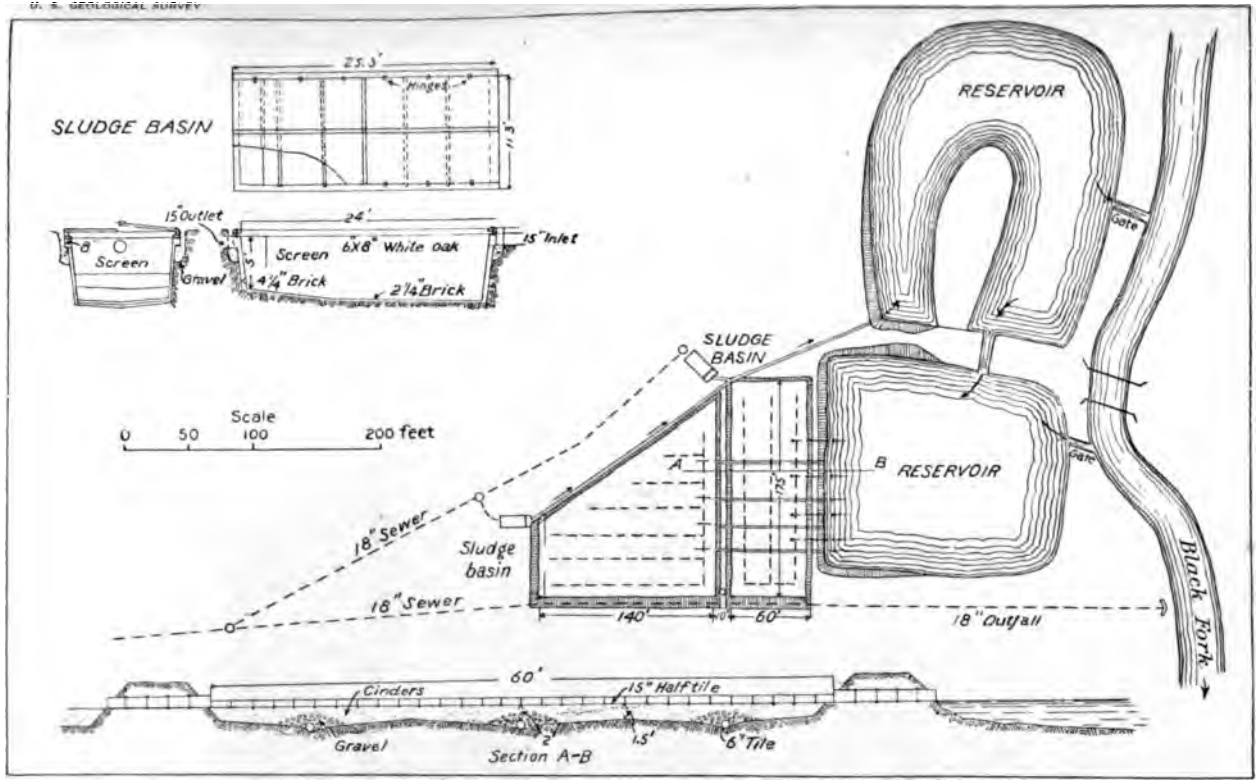
Verdict for the plaintiff was returned, damages being fixed at $317. This is at the rate of $6.34 for each acre of plaintiff's bottom land for

the four years to which the statute of limitations confined the consideration of pollution.

The case was appealed to the circuit court of Richland County and then to the supreme court of Ohio, the judgment of the lower court being affirmed in each case.

A careful review of the testimony given at the trial convinces one that the acid-iron pollution rendered the stream less suitable for domestic purposes as a boiler water, as an ice supply, and as a water supply for animals. The riparian rights of landowners below Shelby had been interfered with, and, in the judgment of the jury, interfered with in a substantial degree.

Injury to vegetation or stock was, to say the least, problematic. The only evidence offered indicating such injury was circumstantial and merely indicated the possibility of such injury. The claim for injury to vegetation was based on the flooding of lands. From the plaintiff's testimony it appears that the cross section of the stream at his farm is about 150 square feet, and the stream at lowest flood must carry at least 30,000 pounds of water per second. Only 6,000 pounds of 78 per cent acid are used at the tube works in a day, and nearly all of this is converted into iron sulphate before it is discharged as waste. From a scientific standpoint, therefore, it seems incredible that by any means the pollution arising from this acid, or ten times as much acid, could noticeably affect the pasture land or crops. Were the waste liquor stored for days and discharged only at time of stream flood (a practice that was not followed to any great extent), it would not pollute the water sufficiently to kill vegetation by merely washing over it. It is of course physically impossible under the conditions existing that any free acid should be in the stream after the polluting liquors have been thoroughly mixed with the stream water. The alkalinity of the Black Fork at its lowest dry-weather flow is sufficient to neutralize twice as much acid as is used at the tube works were the acid not already nearly neutralized in the pickling process before being discharged into the stream. It is to iron oxides and sulphates that we must look for injurious pollution; but with added information regarding the qualities of these substances the probability of ill effects upon vegetation grow still fainter. In Thorpe's Dictionary of Applied Chemistry, vol. 2 (1891), page 367, we find the statement that the coloring matter of clays is chiefly iron oxide, and clays, except so far as by their compactness and impermeability they prevent the percolation of water, certainly are not injurious to vegetable life. Furthermore, on page 368 of Thorpe's Dictionary we find the following statement concerning ferrous sulphate: "In weak solution it is said to promote the growth of certain plants, especially of roots."



PLAN OF SEWAGE-DISPOSAL PLANT AT SHELBY, OHIO.

Injury to stock depends upon a different set of conditions. The time of lowest stream flow in dry weather would be the time of greatest pollution. It is possible that large charges of waste pickle at such times might at certain hours of the day produce a pollution which would be injurious to animal life, for although iron sulphates and oxides are beneficial in small quantities and are largely used in tonics for human consumption, great amounts of the sulphates might do harm. The testimony was more or less conflicting upon this point, but a careful review of all statements leads to the conclusion that probably no actual injury was suffered by stock because of the condition of the stream water.

The winning of this action by the farmers was followed by a succession of suits for damage to lands farther downstream. This sort of litigation has been kept up intermittently until the present time, when three or more suits, recently filed, are awaiting trial.

The discharge of pickling wastes into the city sewers, with more or less direct pollution of the stream, was continued until August, 1904, when a plant was installed for disposing of the strong iron-sulphate liquors by converting them into crystal copperas. A full description of this plant is given later. At this point it will be sufficient to state that one-fifth of the acid used is thus recovered as a commercially marketable substance. Waste of valuable material and stream pollution are therefore obviated by this plant to a considerable extent. No further changes have been made in the disposal of the waste pickle, except that the copperas plant was enlarged somewhat in June, 1905.

At present, therefore, a part of the waste liquor from the pickling process is recovered as copperas; a part is discharged into the city sewers, passes through the sewage-purification works, and thence to Black Fork, and the remainder flows into Red Brook and thence to Black Fork.

EFFECT OF ACID-IRON LIQUORS UPON SEWAGE PURIFICATION PROCESSES.

GENERAL CONDITIONS.

To understand the discussion that follows, no detailed knowledge of the polluting liquors is necessary beyond a mere recognition of the fact that they consist chiefly of iron sulphate, with an admixture of iron oxides and free sulphuric acid in varying quantities.

A brief description of the sewage-disposal plant at Shelby (see Pl. I) is, however, essential. The plant is located about 3 miles north of Shelby on a 25-acre tract owned by the city and known as "the sewer farm." An 18-inch sewer from the city acts as a gravity conduit for the sewage, which amounts to 250,000 or 300,000 gallons a

day, varying in quantity with the amount of ground water that finds entrance to the system. Rough measurement by the writer in July, 1905, indicated a flow of about 275,000 gallons. The sewage first enters a sludge basin for the removal of the larger suspended matter, a wire screen of ½-inch mesh being placed over the exit. There are two of these basins, which are used alternately. Each is of brick, 10 by 24 feet and 6 feet deep, and contains about 8,000 gallons. It is customary to use one basin about three months and then to pump out the accumulation of sludge for use as manure on the farm. The sludge is said to be an excellent fertilizer and promotes the growth of unusual crops.

From the sludge basin the sewage flows through two shallow reservoirs, together holding about five days' flow, which are arranged in series, and thence is distributed by half-tile carriers over filter beds of cinders and gravel. The filters are two in number and have a total area of 25,000 square feet. Six-inch underdrains are laid 20 feet apart in depressions and covered with a 6-inch layer of gravel 6 or 8 feet wide, the sides of the depressions sloping to the drains. The whole is then covered by 18 inches of cinders averaging one-fourth inch in diameter. The underdrains lead to an 18-inch outfall sewer, which discharges into Black Fork a few yards away. The filters are used only during the warm months and receive no attention except an occasional weeding. A by-pass provides for the discharge of raw sewage into the outfall sewer, and gates lead from each reservoir to the stream. The whole plant is subject to occasional overflow of high water from Black Fork.

As originally constructed the sludge basins discharged upon the filter beds. Because of rapid clogging the smaller, and later the larger, sedimentation reservoir was constructed, with beneficial effect.

When visited first by the writer in February, 1905, the filter beds were not in use, while on the second visit, in July of the same year, they were both being flooded. They showed every evidence of being badly clogged, the sewage standing over them to a depth of 18 inches. Only about half the sewage passes through the beds in any case, the remainder escaping to the stream by infiltration through the banks or by direct flow from the leaky waste gates of the reservoirs. Black Fork, which passes by the full length of both reservoirs, receives a large part of this waste flow, as is indicated in the stream by a strong discoloration of iron oxide. Indeed, a superabundance of iron oxide is apparent about the whole plant. The filtering material of the filter beds and the banks of beds and reservoirs are heavily coated with it. The sewage flow also is frequently highly discolored, especially as it nears the filter beds. The effluent from the beds is clear and free from suspended matter, but upon standing becomes turbid and receives a reddish cast from precipitation of

iron. There is a lack of odor about the plant generally, which doubt due to the presence of a great quantity of ferrous sulp in the sewage. The odor is noticeably greater in summer, how than in winter. During the warm months a considerable action or gasification is apparent in the shallow reservoirs, especially in the first or smaller one. Much sedimentation place in these ponds, and a thin scum and at places a heavy cr formed upon the surface over a considerable area.

Analyses of sewages at this plant are shown in the table on 14 and 15, which is adapted from the Eighteenth Annual Rep the Ohio State Board of Health (1903), pp. 550–552.

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a "When added to excremental matters, it [ferrous sulphate] absorbs ammonia and other substances and renders the matter almost odorless." Thorpe's Dictionary of Applied Ch vol. 2 (1891), p. 368.

Chemical examination of sewages and effluent from Shelby, Ohio.

[Parts per million.]

BEFORE ACID-IRON WASTES HAD BEEN ADMITTED TO SEWERS. (NORMAL SEWAGE.)

No. of sample.	Description of sample.	Date and hour of collection.	Color.	Turbidity.	Sediment. [a]	Odor. [a]	Oxygen required.	Alb. ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Alkalinity.	Incrusting constituents.	Total solids.	Suspended solids.	Loss on ignition.	Iron.
2042	Raw sewage	December 28, 1901, 8 a. m.–7 p. m.	15	73	Con.	3 sew	11.73	1.404	2.740	0.100	0.92	27.8	197	349	1,044	.....	.....	.....
2045	Raw sewage	December 28–29 1901, 8 p. m.–7 a. m.	16	135	Con.	Oily	28.51	1.608	2.560	.070	.88	22.5	187	332	1,188	.....	.....	.....
2168	Raw sewage	May 7, 1902, day	37	300	Con.	4 sew	26.11	2.780	3.800	None.	Tr.	27.6	270	210	1,042	.....	275	.....
2172	Raw sewage	May 7–8, 1902, night	20	98	Con.	4 sew	11.38	1.350	3.930	.056	.35	47.6	252	.....	914	.....	252	.....
	Average		22	152	Con.	4 sew	19.43	1.786	3.258	.056	.54	31.4	226	297	1,047	.....	264	.....
2043	Sludge-basin effluent	December 28, 1901, 8 a. m.–7 p. m.	18	90	Con.	Musty, 1 oily.	13.09	.896	3.520	.076	.88	27.3	197	360	1,035	.....	.....	.....
2046	Sludge-basin effluent	December 28–29, 1901, 8 p. m.–7 a. m.	17	73	Con.	Musty, oily.	9.62	.632	2.508	.060	.92	23.5	183	345	928	.....	.....	.....
2169	Sludge-basin effluent	May 7, 1902, day	22	20	Dec.	4 sew	5.73	2.260	3.450	.060	.50	25.4	246	208	851	.....	225	.....
2173	Sludge-basin effluent	May 7–8, 1902, night	20	16	Dec.	3 sew	8.53	.960	3.370	.052	.50	37.0	252	.....	860	.....	273	.....
	Average		19	50	Dec.	3 sew	9.24	1.187	3.212	.062	.70	28.3	239	304	918	.....	249	.....
	Per cent removed.		14	67	.....	.....	52	34	1.4	[b] 11	[b]30	9.9	[b] 5.8	[b].4	12	.....	5.7	.....
2170	Effluent of small reservoir	May 7, 1902, day	20	Sl.	Sl.	3 sew	5.41	.750	2.830	.062	.50	29.7	235	198	846	.....	208	.....
2174	Effluent of small reservoir	May 7, 1902, night	22	Sl.	Sl.	3 sew	6.22	.780	3.090	.054	.55	28.3	239	.....	832	.....	259	.....
	Average		21	Sl.	Sl.	3 sew	5.82	.765	2.960	.058	.52	29.0	237	198	839	.....	234	.....
	Per cent removed.		4.5	75	.....	.....	70	57	9.1	[b]3.6	3.7	7.7	[b]4.9	33	20	.....	11	.....
2044	Filter-bed effluent	December 28, 1901, 8 a. m.–7 p. m.	6	Tr.	Tr.	Musty	2.42	.260	2.580	.076	.56	23.7	197	360	960	.....	.....	.....
2047	Filter-bed effluent	December 28–29, 1901, 8 p. m.–7 a. m.	5	Tr.	Tr.	Musty	3.01	.268	3.100	.032	.64	25.7	183	350	951	.....	.....	.....

2171	Filter-bed effluent	May 7, 1902, day	19	Tr.	Tr.	1 musty.	3.78	.360	2.800	.060	.40	32.0	230	223	817	.....	208	.....
2175	Filter-bed effluent	May 7-8, 1902, night	18	Tr.	Tr.	1 musty.	2.90	.330	3.280	.110	.60	29.7	214	.....	805	.....	240	.....
	Average		12	Tr.	Tr.	1 musty.	3.03	.308	2.940	.070	.55	27.8	206	311	883	.....	227	.....
	Per cent removed.		45	90	90	80	84	83	9.8	b25	b1.8	11	8.7	b4.7	16	.....	14	.....

AFTER ACID-IRON WASTES HAD BEEN DISCHARGED INTO SEWERS FOR SEVERAL MONTHS. (ACID-IRON SEWAGE.)

3359	Raw sewage	December 15, 1903, 2 p. m.	.....	.....	.....	.....	307	1.890	3.560	.000	0 (?)	.....	4,430	.....	7,397	173	1,826	100+
3360	Sewage-basin effluent	December 15, 1903, 2 p. m.	.....	.....	.....	.....	129	1.700	3.610	Tr.	0 (?)	.....	1,456	.....	2,558	437	801	100+
	Per cent removed.		.....	.....	.....	.....	58	11	1.4	.....	0	.....	c 67	.....	65	b 153	56	.....
3361	Reservoir effluent	December 15, 1903, 2 p. m.	.....	.....	.....	.....	33	1.200	2.150	.024	0 (?)	.....	990 acid	.....	1,523	224	412	100+
	Per cent removed.		.....	.....	.....	.....	89	37	40	.....	0	.....	c 78	.....	79	b 29	77	.....
3362	Filter-bed effluent	December 15, 1903, 2 p. m.	.....	.....	.....	.....	24.8	.300	3.150	.018	0 (?)	.....	13 acid	.....	1,534	201	309	100+
	Per cent removed.		.....	.....	.....	.....	91	84	12	.....	0	.....	c 99.7	.....	79	b 16	83	.....

a Abbreviations: Sl., slight; tr., trace; con., considerable; dec., decided; sew., sewagic. The numbers indicate the intensity of the odor according to the following scale: 0, no odor perceptible; 1, distinct; 2, considerable; 3, decided; 4, strong.

b Increase.

c Removal of acidity.

The samples of 1901 were taken before either reservoir had been constructed, the effluent of the sludge basin being then passed directly to the filters; the samples of 1902 were taken after the first or smaller settling reservoir had been built, and the samples of 1903 were taken after both reservoirs were in use.

The first part of the table shows a rather dilute sewage, ground water doubtless having access to the long outfall sewer in considerable quantity. The presence of nitrites and nitrates indicates that a supply of oxygen is available, though we have no corroboration of this. The nitrites, nitrates, and relatively high free ammonia indicate putrefaction in the sewers in about the stage one would expect from the somewhat wide separation of city and disposal plant, about three hours being required for the sewage to pass from the city to the plant.

It is of interest to note that the sludge basin, through which the sewage passes in from one-half to three-fourths of an hour, has more effect in reducing the organic matter than any other one feature of the purification plant. By oxygen required the reduction is 52 per cent and by albuminoid ammonia 34 per cent. A reduction of 12 per cent in total solids is accomplished. The larger reduction in oxygen required and the increase in nitrites and nitrates indicate rather vigorous oxidation, presumably accomplished by oxygen dissolved in the sewage.

In the small sedimentation reservoir, which affords one day for settling, anaerobic conditions seem to have been established to some extent. The free oxygen is doubtless used up, and then the nitrites and nitrates are robbed of their oxygen to assist in breaking up the carbonaceous matter. By oxygen required a reduction of 18 per cent and by albuminoid ammonia a reduction of 23 per cent is effected by the reservoir.

The filters accomplish 14 per cent purification by oxygen required and 26 per cent by albuminoid ammonia. The entire plant shows a very good percentage of reduction. The effluent, having a slight musty odor, would seem to be somewhat putrescible, but is not chemically a poor one. It can not be regarded as a source of serious pollution of the stream into which it is discharged, even at lowest flow.

It is worth while to note that, although, owing to the construction of the sedimentation reservoir, the sewage flowing to the filters was in much better condition in 1902 than in 1901, the effluent is decidedly worse. This indicates deterioration of the filters from overwork and neglect.

The latter part of the table, giving the tests of 1903, shows a sewage in which the "acid-iron" conditions are extreme. Iron is present in large quantity and the acidity is very high, probably sufficient to prevent bacterial action. Another characteristic feature is the high value for oxygen required, the figures being practically a measure of the ferrous salts present and affording no information regarding the

carbonaceous matter. The very high solids and loss on ignition are also worthy of special notice. The loss on ignition in this case bears scant relation to the organic matter present. The albuminoid and free ammonia tests show a rather small amount of organic matter and a somewhat advanced stage of putrefaction. The diminution in acidity is surprisingly rapid. No doubt some rather complicated reactions, including a circle of reduction and oxidation, take place, the results of which are largely the change from ferrous to ferric salts and the deposition or gaseous escape of sulphur compounds at the expense of the free acid. This determination is borne out by the similar diminution in total solids and oxygen required. The organic matter is reduced but little in the early processes of the disposal plant, but is removed chiefly by the filters.

The effluent is a very good one from a sanitary standpoint, so far as may be judged from the analyses under consideration. The little free acid it contains can not be considered as an objectionable addition to the highly alkaline waters of Black Fork. The high oxygen-absorbing power, however, would tend to produce conditions unsuitable for fish life and the extreme amount of iron would render the stream unsightly and its waters unfit for domestic use.

In the following table will be found analyses of sewage samples taken by the writer in 1905. This set of samples differs from those of 1903 chiefly in the fact that the acid-iron waste is less in the later samples by reason of the installation of a copperas plant at the tube works. Of the determinations in the table, dissolved oxygen, acidity, sulphates, and iron, and the plating of bacteriological samples and preparation of cultures for transplanting were the work of the writer. The remaining work is all that of officials of the laboratory of the Ohio State Board of Health. The following methods of analyses were used: Organic nitrogen, Kjeldahl; free ammonia, distillation; residue in platinum, drying at 100°; chlorine, silver nitrate with potassium chromate; oxygen required, boiling five minutes; acidity, sodium carbonate tablets with methyl orange indicator; sulphates, candle turbidimeter; iron, colorimetric; putrescibility, incubation five days at 37°. Regarding the methods referred to in brief that are not in general use, it may be mentioned that those used for acidity, sulphates, and iron are the field methods of the United States Geological Survey.

This table shows a strong acid-iron sewage with a moderate content of organic matter. The acid-iron element is greater in the night than in the day sewage. Owing to the iron sulphate the sewage is only moderately putrescible by odor upon incubation. The bacterial content is very low, probably one-fourth that of a purely domestic sewage of similar concentration. The effect of the acid is shown in reduction of bacteria from day to night, and more strikingly in reduction of acid-forming bacteria, to which the acidity appears to be specially unfavorable.

Analyses of sewage from the sewage-purification plant at Shelby, Ohio. (Modified sewage.)

[Parts per million.]

Source.	Date, July, 1905.	Organic nitrogen.	Free ammonia.	Residue on evaporation.			Oxygen required.	Dissolved oxygen.	Acidity, as $CaCO_3$.	Sulphates, as SO_3.	Iron, as Fe.	Putrescibility.	Bacteria per cubic centimeter.	Red colonies per cubic centimeter in lactose litmus agar.	B. coli communis isolated from 1 cubic centimeter culture.
				Total.	Dissolved.	Suspended.									
Raw sewage, day	12	2.94	3.50	3,492	3,233	259	130.8	0.0	156	1,980	500	+	(a)	600	.....
Raw sewage, day	13	2.61	3.25	3,142	3,128	14	108.8	0.0	201	.....	600	+	325,000	(a)	.....
Average	12-13	.278	3.38	3,317	3,180	136	119.8	0.0	178	1,980	550	+	325,000	600	.....
Raw sewage, night	12-13	2.34	3.00	4,062	3,942	120	38.8	0.0	558	2,210	.....	+	350,000	b 0	.....
Raw sewage, night	13-14	2.59	2.66	3,710	3,657	53	121.7	0.0	502	2,390	500	+	200,000	4	.....
Average	12-14	2.46	2.83	3,886	3,800	86	130.2	0.0	530	2,300	500	+	275,000	4	.....
General average	12-14	2.62	3.10	3,602	3,490	112	125.0	0.0	354	2,140	525	+	300,000	302	.....
Reservoir effluent	12-13	1.10	4.00	2,116	2,012	104	66.2	0.0	116	1,730	675	Tr.	2,000	b 0	—
Reservoir effluent	13-14	1.07	3.75	2,569	2,464	105	83.6	0.0	162	1,440	500	Tr.	2,800	40	.....
Average	12-14	1.08	3.88	2,342	2,238	104	74.9	0.0	139	1,583	585	Tr.	2,400	40	—
Per cent removed	.....	59.00	c 25	35	.....	.....	40	.....	61	26	.....	.....	99.2	.....	.....
Filter-bed effluent	12-13	.74	4.00	2,062	1,798	264	46.2	0.0	6	1,310	625	—	2,000	b 0	—
Filter-bed effluent	13-14	1.30	4.00	2,312	2,109	203	58.9	0.0	44	1,310	350	—	1,100	b 0	—
Average	12-14	1.02	4.00	2,187	1,954	234	52.6	0.0	25	1,310	485	—	1,550	b 0	—
Per cent removed	.....	61.00	c 29	39	.....	.....	58	.....	93	39	8	100	99.5	100	.....

a Lost, overgrown, or slipped.

b In 0.05 cubic centimeter sample.

c Increase.

The effluent is, organically, a fair one from a chemical standpoint d is nonputrescible. Bacteriologically it is very good, containing t a small number of bacteria, and these not of the colon family. s content of iron sulphates, however, makes it unsuitable for addi- n to any but a very large stream.

It will be observed that the filters take but little part in the purifi- tion. From their physical aspect this was to be expected, although e extent of their deterioration is surprising. Their chief value at esent seems to be in accomplishing a reduction in acidity and ygen-absorbing power. The plant accomplishes an organic purifi- tion of about 60 per cent and a reduction in mineral matter between and 40 per cent.

The values obtained for suspended solids are subject to variation, ring to a gradual precipitation of iron, especially from the effluent. ie absence of dissolved oxygen serves to show more decidedly the idity for oxygen possessed by ferrous sulphate. The large reduc- on in sulphates is not unlooked for, but the permanence of the iron surprising. One would naturally expect the sulphates to be the ore persistent.

A comparison of the three sets of analyses and their relative con- litions will assist in answering the following questions, which are f general interest in their relation to sewage disposal in those cities where acid-iron liquors are encountered:

1. How does a disposal plant—consisting of sludge basin, large, shallow sedimentation reservoirs, and cinder and gravel filters—affect acid-iron sewage as compared with domestic sewage?

2. How is such a plant affected by these two classes of sewage?

3. Should large quantities of acid-iron liquors be admitted to a sewerage system?

4. Is a copperas-recovery plant of value as a means of preventing the overcharge of sewage with such liquors?

TOTAL SOLIDS.

Reduction in total solids occurs chiefly in the sludge basin and reservoirs, the filters having little or no effect on any of the sewages considered. Such effect of filters as is shown by analyses is less than the sampling error. In sludge basin and reservoirs the per cent of solids removed increases with the increase of solids in the sewage. By far the greater part is removed in the sludge basin, and the ratio of per cent removed by sludge basin to per cent removed by reservoir increases with the increase in solids in the sewage.

Effect of acid-iron wastes, and of such wastes modified by a copperas-recovery plant, upon the efficiency of sewage-purification processes at Shelby, Ohio.

[Parts per million and percentage removed.]

	Oxygen required.		Organic nitrogen.		Albuminoid ammonia.		Free ammonia.		Nitrites.		Nitrates.		Alkalinity.		Total residue.		Loss on ignition.	
	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.	Parts per million.	Per cent.
Sludge basin:																		
(*a*) Normal sewage	10.19	52	.....	.....	0.599	34	0.046	1.4	−0.006	−11	−0.16	−30	− 13	− 6	129	12	15	6
(*b*) Acid-iron sewage	178.00	58	.....	.....	.190	11	− .050	−1.4	Tr.	−∞	.00	0	−2,974	− 67	4,839	65	1,025	56
Difference (*a*−*b*)	−167.81	− 6	.....	.....	.409	23	.96	2.8	− .006	+	−.16	−30	2,961	61	−4,710	−53	1,010	−50
Sedimentation reservoir:																		
(*a*) Normal sewage (1 day)	3.42	18	.....	.....	.422	23	.252	8	.004	7	.18	33	2	1	79	8	15	6
(*b*) Acid-iron sewage (5 days)	96.00	31	.....	.....	.500	26	1.460	41	− .024	−∞	.00	0	− 466	− 11	1,035	14	389	21
Difference (*a*−*b*)	− 92.58	−13	.....	.....	− .078	− 3	−1.218	−33	.028	+	.18	33	468	12	− 956	− 6	− 374	−15
Basin and reservoir combined:																		
(*a*) Normal sewage	13.61	70	.....	.....	1.021	57	.298	9	− .002	− 4	.02	4	− 11	− 5	208	20	30	11
(*b*) Acid-iron sewage	274.00	89	.....	.....	.690	37	1.410	40	− .024	−∞	.00	0	−3,440	− 78	5,874	79	1,414	77
(*c*) Modified acid-iron sewage	50.10	40	1.54	59	.....	.....	− .780	−25	.....	.....	.00	0	− 215	− 61	1,260	35	.....	.....
Difference (*a*−*b*)	−260.39	−19	.....	.....	.331	20	−1.112	−31	.022	+	.02	4	3,429	73	−5,614	−59	−1,384	−66
Difference (*a*−*c*)	− 36.49	30	.....	.....	.....	.....	1.078	34	.....	.....	.02	4	204	55	−1,052	−15	.....	.....
Difference (*b*−*c*)	223.90	49	.....	.....	.....	.....	2.190	65	.....	.....	.00	0	−3,225	− 17	4,612	44	.....	.....
Filter beds:																		
(*a*) Normal sewage	2.79	14	.....	.....	.457	26	.020	1	− .012	−21	.03	− 6	31	14	− 44	− 4	7	3
(*b*) Acid-iron sewage	8.20	3	.....	.....	.900	48	−1.000	−28	.006	−∞	.00	0	− 977	− 22	− 11	0	103	6
(*c*) Modified acid-iron sewage	22.30	18	.06	2	.....	.....	− .120	− 4	.....	.....	.00	0	− 114	− 32	155	4	.....	.....
Difference (*a*−*b*)	− 5.41	11	.....	.....	− .443	−22	1.020	29	− .018	−	−.03	− 6	1,008	36	− 3.3	− 4	− 96	− 3
Difference (*a*−*c*)	− 19.51	− 4	.....	.....	.....	.....	.140	5	.....	.....	−.03	− 6	145	46	− 199	− 8	.....	.....
Difference (*b*−*c*)	− 14.10	−15	.....	.....	.....	.....	− .880	−24	.....	.....	.00	0	− 863	10	− 166	− 4	.....	.....
Entire plant:																		
(*a*) Normal sewage	16.40	84	.....	.....	1.478	83	.318	10	− .014	−25	−.01	− 2	20	9	164	16	37	14
(*b*) Acid-iron sewage	282.20	92	.....	.....	1.590	84	.410	12	− .018	−∞	.00	0	−4,417	−100	5,863	79	1,517	83
(*c*) Modified acid-iron sewage	72.40	58	1.60	61	.....	.....	− .900	−29	.....	.....	.00	0	− 329	− 93	1,415	39	.....	.....
Difference (*a*−*b*)	−265.80	− 8	.....	.....	− .112	− 1	− .092	− 2	.004	+	−.01	− 2	4,437	109	−5,699	−63	−1,480	−69
Difference (*a*−*c*)	− 56.00	26	.....	.....	.....	.....	1.218	39	.....	.....	−.01	− 2	349	102	−1,251	−23	.....	.....
Difference (*b*−*c*)	209.80	34	.....	.....	.....	.....	1.310	41	.....	.....	−.01	0	−4,088	− 7	4,448	40	.....	.....

The removal of solids in the acid-iron sewage occurs probably in greatest measure as sedimentation of certain compounds after chemical change by reduction, oxidation, and substitution. Next comes the influence of water of crystallization. Total residue, as determined upon the water bath, includes water of crystallization for both ferrous and ferric sulphates. Oxidation from the ferrous to ferric sulphate is accompanied by a loss of 36 per cent of such water, which is, of course, thus lost to the total residue determination. It seems probable that about three-fourths of the reduction in solids can be attributed to sedimentation, nearly all the remainder to change from ferrous to ferric compounds, and a little residue to the escape of volatile compounds.

The effect upon the plant of the increased deposition of solid matter after the acid-iron waste has been introduced will be rapid loss of efficiency of sludge basin, which can be prevented only by frequent cleaning. The same effect will appear in the sedimentation reservoirs to a lesser extent, particularly with "modified" sewage. Furthermore, the fact that reduction by filters is so much greater for "modified" sewage indicates a less complete purification in the preceding processes, and consequent crowding of filters, to their detriment.

The copperas plant appears to effect about 60 per cent reduction in the solids in the raw sewage, due to the acid-iron liquors.

LOSS ON IGNITION.

For this determination we have comparison only on normal and acid-iron sewages. The ratio of loss on ignition to total residue is nearly the same in both cases, being slightly less for the acid-iron sewage. Loss on ignition for the acid-iron sewage would appear to be due largely to breaking up of water of crystallization. The variation of the ratio of loss on ignition to solids and its decrease by oxidation of ferrous salts therefore affords a means of rough comparison of oxidation and sedimentation in the purification processes. Sedimentation seems to be the greater force in the sludge basin, but is unable to keep pace with oxidation in reservoirs and filters. In other words, the combined forces tending to a reduction of solids act more vigorously in the sludge basin and less vigorously in the reservoirs and filters than does the single force of oxidation. The variation is not, however, extensive.

OXYGEN REQUIRED.

This determination means two different things with the different classes of sewage. With normal sewage it may be taken as an approximate proportional measure of the carbonaceous material. With acid-iron and modified sewages it measures the ferrous salts

also, and these are so abundant, the carbonaceous matter being comparatively insignificant, that its value as a measure of organic matter is nil. For the latter classes of sewage therefore the oxygen required may be assumed with but little error to be a measure of ferrous salts present in the sewage. Loss in oxygen required will therefore be proportional to decrease of ferrous salts. Decrease of ferrous salts probably occurs in this case in two ways—(1) by reduction of ferrous sulphate to iron sulphide and sedimentation of the iron sulphide, and (2) by oxidation of ferrous to ferric sulphate. Just what changes take place we have not sufficient data to determine, but it seems probable that at Shelby the former is the more prominent reaction in the sludge basin and the latter predominates in reservoirs and filters. This conclusion is borne out by the fact that the ratio of loss on ignition and of oxygen required to total solids increases from raw sewage to sludge basin effluent and decreases thereafter.

The ratio of loss on ignition to oxygen required for acid-iron sewage is practically constant in sludge basin and filters, but undergoes a slight increase in the reservoirs. This is in marked contrast to the variation in the similar ratio for normal sewage, which undergoes rapid increase as the sewage passes through the works. This ratio offers the most distinctive difference in the action of the purification processes upon the two sewages.

ALBUMINOID AMMONIA AND ORGANIC NITROGEN.

Albuminoid ammonia for normal and acid-iron sewages and organic nitrogen for modified sewage are the only determinations from which may be gathered the comparison of effect of plant upon the organic matter of the sewages considered. The sludge basin appears to cause three times as much reduction in organic matter for normal as for acid-iron sewage; the reservoirs seem to have about the same effect upon the two, while the filters offset the effect of the sludge basin, making the effluents of about equal purity. Although the organic nitrogen of modified sewage should not be directly compared with the albuminoid ammonia of normal and acid-iron sewage, a general consideration of these determinations would seem to indicate equally as good reduction for modified as for normal sewage in sludge basin and reservoirs, but practically no reduction is secured by the filters on modified sewage. From the condition of the filters this last result was to be expected.

It may safely be said that the introduction of acid-iron wastes interferes with the reduction of organic matter in sludge basin and reservoirs, and thus tends to crowd work upon the filters. The effect upon the plant will be a more rapid decrease of efficiency than would otherwise be the case. The copperas plant is beneficial in alleviating these conditions, apparently to a very great extent.

FREE AMMONIA.

s determination shows wide variation under the different con-
s. With normal sewage there is a slight but persistent decrease
ammonia in all the purification processes, the greatest decrease
found in the reservoirs. With the strong acid-iron sewage
is a slight increase in the sludge basin, a very great decrease in
dimentation reservoirs, and, finally, a great increase in the
It appears as though the saline nitrogen in sludge basin and
is held in the sewage, while the reservoirs allow a very con-
ble escape of nitrogen gases. With the modified sewage there
teady increase in free ammonia throughout the plant. Evi-
the absorbing power of iron sulphate and the combining
of the free acid in acid-iron sewages tend to hold in the sewage
itrogen or nitrogenous compounds, but under favorable con-
s these volatile substances may escape to a greater or less
.

NITRITES AND NITRATES.

addition of acid-iron waste to the sewage very largely dimin-
the nitrites and causes the nitrates to disappear entirely in all
wages examined. This action is doubtless due to the reducing
ies of the iron sulphate and bears no relation to organic purifi-
.

ALKALINITY.

alkalinity of normal sewage is affected but little by the purifi-
processes. The acid-iron sewage, on the other hand, with its
acidity, undergoes great change and is practically neutralized
action of the disposal plant. Most interesting is the reduction
dity by the filters. Apparently they provide conditions spe-
favorable for change from ferrous to ferric sulphate, and the
cid is thus used up. The effect of the acid upon the plant is to
ere seriously with bacterial action and in so doing to destroy in
measure the pathogenic quality of the sewage.

SUMMARY.

Introduction of acid-iron waste into domestic sewage (*a*) largely
ses its total solids, loss on ignition, iron, sulphates, and oxygen
ed, causes the disappearance of nitrites and nitrates, and
es it to a highly acid liquid; (*b*) reduces the effect of the
basin upon organic matter, and tends toward a rapid deterio-
of every part of the sewage-disposal plant; (*c*) interferes with
ial action, but in so doing lessens the harmful quality of sewage;
duces obnoxious odors from the sewage and reduces its putres-
y by absorption of gases; (*e*) renders the effluent of the sewage-

purification works unfit to enter any but a very large stream because of its content of iron sulphates.

2. A sewage-disposal plant consisting of sludge basin, five-day sedimentation reservoirs, and cinder and gravel filter beds (*a*) removes organic matter from highly acid-iron sewage as completely as from domestic sewage; (*b*) affords less freedom from free or saline ammonia when treating acid-iron sewage; (*c*) accomplishes greater reduction but affords a worse effluent as regards oxygen required when treating acid-iron sewage; (*d*) renders extremely acid sewage nearly neutral but affects the alkalinity of domestic sewage very little; (*e*) affords an effluent with one-fourth the quantity of nitrites in acid-iron as in domestic sewage, but with no nitrates or dissolved oxygen in acid-iron sewage; (*f*) may reduce total solids as much as 79 per cent in acid-iron sewage, while domestic sewage is reduced not more than 20 per cent; (*g*) reduces sulphates in same proportion as total solids but affords only slight decrease in iron content of acid-iron sewage; (*h*) lessens the number of bacteria in acid-iron sewage by 99.5 per cent and frees it from *B. coli communis* and other acid-producing bacteria.

3. The installation of a copperas plant recovering 20 to 25 per cent of the acid used in pickling, such plant treating the wastes before they enter the sewers, reduces the harmful effects of acid-iron sewage upon such a disposal plant by about 60 per cent, and in consequence reduces in like proportion the attention requisite for proper maintenance of the plant. The copperas plant, however, will not take the place of attention to the sewage processes; a better effluent may be obtained with an extremely concentrated acid-iron sewage and careful attention than with a 60 per cent better sewage without the attention.

In connection with these conclusions, based upon meager and fragmentary data, it will be of especial interest to review the conclusions of Kinnicutt and Eddy, based upon two years' constant work upon Worcester sewage. This sewage is about 4⅓ times as strong, organically, as the sewage here considered, but contains only 10 per cent as much solid matter and 4 per cent as much free acid as what is here designated "acid-iron" sewage, and 22 per cent as much solid matter 24 per cent as much iron, and 50 per cent as much free acid as what is here termed "modified" sewage. The results of Kinnicutt and Eddy's work, quoted below, from pages 44 and 45 of the Fourth Report of the Connecticut Sewerage Commission, 1902, are based upon observations of the slow passage of such sewage through a closed septic tank. From this summary of results it appears—

That about one-fourth of the total solid matter contained in the sewage will be removed.

That the effluent from the tank will contain about 20 per cent less soluble matter than the crude sewage, owing to the soluble matter in the sewage being decomposed or changed *into insoluble* substances.

ıat the amount of suspended matter removed from the sewage will not greatly exceed er cent unless special precautions are taken to retain in the tank the finely divided sulphide formed by the reduction of the soluble iron sulphate in the sewage.

ıat the amount of organic matter removed from the sewage as determined from the minoid ammonia will average from 20 to 25 per cent.

ıat of the suspended organic matter the amount removed will average a little under 50 :ent, and that the amount of soluble organic matter removed will not average much › than 10 per cent of the soluble organic matter in the sewage.

ıat of the suspended matter taken out of the sewage in its passage through the tank, 60 to 70 per cent will remain in the tank and have to be removed; only from 30 to 40 :ent of the arrested suspended matter being changed by the action of the bacteria into ›le or gaseous substances

ıat the amount of sludge that will have to be handled when it is necessary to clean out ank will not, however, equal 60 or 70 per cent of the weight of the sludge that would be ed from the removal of the same amount of suspended matter in a sedimentation tank, will not be more than 50 per cent of this amount, owing to the fact that the sludge in a c tank contains less water than the sludge in a sedimentation tank.

ıat with an acid-iron sewage containing street washings the amount of mineral matter ıe sludge will be about 50 per cent of the total solid matter in the sludge, and of this :ral matter over one-third will be found to be iron sulphide

ıat decomposition of the sludge, as shown by the evolution of gas, will take place in er as well as in summer if the temperature of the sewage in the tank does not fall below Fahrenheit, but the rate of decomposition will be much slower, one-half of what it is in mer.

ıat the amount of gas evolved from the septic tank with a sewage similar to Worcester ge and having about the ame range temperature as Worcester sewage, will average a › over one-half a cubic foot for every 100 gallons of sewage passed through the tank, rate of flow of the sewage through the tank being eighteen hours. In the warmest ths the amount evolved will, however, be about 1 cubic foot; in the coldest months ıt one-fourth of a cubic foot.

hat the gas given off from a septic tank with acid-iron sewage does not contain hydro- or sulphide of hydrogen, but a mixture of marsh gas, carbon dioxide, and nitrogen, in ut the following proportions: Marsh gas, 75 per cent; carbon dioxide, 6 per cent; ogen, 19 per cent.

PRESENT CONDITIONS ALONG THE STREAM.

In July, 1905, an investigation was made of conditions along ack Fork for 7 miles below Shelby. Pollution by acid-iron wastes s easily apparent at two points. The first is at the mouth of the all stream (Red Brook) which passes by the tube works. This eam obviously receives acid-iron liquors, presumably the wastes m the pickling tubs and the copperas plant hereinafter described. ıe waters are highly colored with iron, and numbers of small dead nnows were found below the tube works. Lack of oxygen in the ıter was the apparent cause of their death, the fish coming to the rface gasping for breath and finally giving up the struggle, floating wnstream belly upward. A short distance below the tube works is stream empties into Black Fork and gives its waters a high iron coloration. For a few hundred yards below this point Black Fork shallow and its current rapid. Then follow a succession of deep

pools of slowly moving water. These conditions are ideal for the oxidation and sedimentation of the iron. Consequently, more than three-quarters of a mile below the tube works no discoloration is noticeable.

The extent of the pollution is shown roughly by the following table:

Effect of tube works effluent upon Red Brook.

[Observations made July 13, 1905; in parts per million.]

Location.	Iron as Fe.	Sulphuric acid as SO_4.	Alkalinity as $CaCO_3$.	Dissolved oxygen.	Period.
One-half mile above tube works.	3.0	120	180	5.6	
One-fourth mile below tube works, one-fourth hourly composite	32.5	285	190	0.0	64.5 a. m. to 8.30 a. m.
Do	40.0	285	190	0.0	8.45 a. m. to 10.30 a. m.
Do	180.0	640	74	0.0	10.45 a. m. to 12.30 p. m.
Do	20.0	355	47	0.0	12.45 p. m. to 2.30 p. m.
Do	10.0	355	78	0.0	2.45 p. m. to 4.30 p. m.
Do	25.0	355	89	0.0	4.45 p. m. to 6.30 p. m.
Average below tube works	51.2	380	111	0.0	6.45 a. m. to 6.30 p. m.

The samples analyzed were made up of equal quantities taken from the stream every fifteen minutes during the two-hour periods shown by the table. The absence of dissolved oxygen in the stream is a point worthy of special notice and indicates the cause of the death of fish. The other determinations show that the polluting liquor contains large quantities of iron sulphates, but little, if any, free acid. At no time during the day was any free acid found in the stream waters, though their alkalinity was considerably decreased. This decrease could be accounted for by the reaction of the iron sulphates with the alkaline carbonates of the stream waters, though it is probable that a little free acid in the waste discharged is the chief contributing factor. A discharge of an increased amount of waste liquor evidently took place just before noon. Barring accidental cause, this circumstance would indicate that the pollution is to a considerable extent under control and not wholly due to uncontrolled leakage. It is estimated that the stream has a flow of about 40,000 gallons per hour. During the working day, therefore, apparently about 1,000 pounds of SO_3 are discharged into the stream at the tube works. Assuming a normal condition at the plant, this amount could come only from liquors wasted at the pickling tubs.

The second point of pollution by iron liquors is at the city sewage farm, 3 miles below Shelby. Beginning on the morning of July 12, a forty-eight-hour test of the efficiency of the sewage-disposal plant was made, samples being taken every hour during that time. The average content of the effluent, in parts per million, for this period is as follows:

Content of effluent of sewage-disposal plant 3 miles below Shelby, Ohio.

Iron as Fe	485
Sulphuric acid as SO_3	1,310
Acidity as $CaCO_3$	25
Dissolved oxygen	0

Rough measurements of the sewage flow show that it was approximately 275,000 gallons a day. Apparently about half of this amount passes out through the effluent pipe, the remainder leaking to the stream from the sedimentation basins. Both effluent and leakage turn the stream waters red, from precipitated iron.

To determine the persistency of the effects of the polluting effluents samples from Black Fork were analyzed at suitable distances below Shelby. The results of these analyses and also of analyses of the polluting liquors are shown in the accompanying table:

Analyses of water of Black Fork and Red Brook near Shelby, Ohio.

[Parts per million.]

	Iron as Fe.	Sulphuric acid as SO_3.	Alkalinity as $CaCO_3$.	Dissolved oxygen.	Date (July, 1905).	Remarks.
Red Brook ¼ mile below tube works.	51.2	380	111	0.0	13	Average of samples taken every 15 minutes from 6.30 a. m. to 6.30 p. m.
Black Fork above mouth of Red Brook.	3.0	70	190	6.4	13	
Black Fork ¼ mile below Red Brook; Smiley street.	3.5	140	190	6.4	13	
Black Fork 1¼ miles below mouth of Red Brook; State street.	3.0	120	170	6.4	13	
Effluent of sewage farm	485.0	1,310	[a]25	0.0	12-13	
Black Fork opposite sewage farm, 3 miles below mouth of Red Brook.	4.0	120	160	6.2	12	100 yards above entrance of effluent.
Black Fork 4 miles below mouth of Red Brook; ½ mile northwest of London.	14.0	320	100	2.6	14	1 mile below sewage farm.
Black Fork 5¾ miles below mouth of Red Brook; Isaac Adams farm.	2.8	185	130	6.3	14	2¾ miles below sewage farm.
Black Fork 7 miles below mouth of Red Brook.	2.0	145	150	6.6	14	4 miles below sewage farm.

[a] Acidity as $CaCO_3$.

It will be noticed that the iron precipitates out very rapidly. One-half mile below the entrance of the small stream it has decreased to within one-half part per million of the iron content of the Black Fork above the point of pollution. At the next sampling point, three-fourths of a mile farther down, it is normal, or, in other words, no pollution by iron can be detected. Opposite the sewage farm the leakage from the sedimentation basins causes a slight increase in iron content, while a mile below the farm an abnormal amount of iron was found. At this point the stream was highly colored by iron sesquioxide. Again, however, the iron quickly precipitates and becomes less 2¾ miles below the sewage farm than it is above Shelby.

This decrease in iron content continues, so that 4 miles below the farm the stream contains one-third less iron than above Shelby.

The influence upon the dissolved oxygen, as would be expected, is in inverse ratio to the influence upon iron content, and the result of this determination corroborates the results previously discussed. In a word, the polluting iron liquor rapidly takes up the oxygen in the stream and is itself precipitated thereby. Judging from the low content of oxygen a mile below the sewage farm, it is evident that the conditions for this distance are adverse to fish life and may cause the death of small fish.

Another effect we would expect would be decreased alkalinity and an increased sulphate content. Reaction of the iron sulphates with the carbonates of the alkaline earths would eventually result in the production of iron oxide, carbonic acid gas, calcium sulphate, and magnesium sulphate. The iron oxide and excess of alkaline earth sulphates would precipitate and the gas would escape. The effect upon the stream, therefore, would be to give it, compared with other streams of this locality, an abnormally high content of incrusting sulphates, or permanent hardness, and a comparatively low alkalinity, or temporary hardness. That such reaction actually occurs is shown by the analyses made.

The effects of pollution by acid-iron wastes at Shelby may therefore be summed up as follows:

1. From the points of pollution to a point varying from one-half mile to 1½ miles below, the natural condition of the stream waters is seriously impaired for general use and detrimental to fish life.

2. Beyond this point no effect can be noticed aside from an increase in permanent hardness and a decrease in temporary hardness of the waters. Such effect is not prejudicial to animal or vegetable life, but damages the value of the water for use in boilers and to a less extent for domestic purposes.

RECOVERY OF COPPERAS FROM ACID-IRON WASTES.

Before entering upon a discussion of the merits of a copperas-recovery plant as a means of disposing of acid-iron wastes, it will be advisable to describe the process which produces such liquors and to show in some detail their characteristic mineral content.

THE PICKLING PROCESS.

To clean iron and steel from rust and scale it is immersed in a solution of acid in tubs or vats of shape and dimensions suitable to accommodate the material to be pickled. In tube works the pickling tubs are naturally long and narrow to accommodate the sections of tubing. In such works the material is pickled before annealing, in

order that this process may have most uniform and perfect results. Moreover, one of the last steps in manufacture is the passage of finished tubing through the pickling baths, after which it is rinsed and oiled, so that it may be shipped in perfect condition. Much of such material is used in boilers and in other places where it is of the utmost importance that rust should be prevented; hence the special precautions. In tin-plate, galvanizing, and other work where iron is coated with another substance, it is necessary that the iron should be clean and free from rust in order that the coating may properly adhere. It is therefore pickled and rinsed before coating. In such works it is frequently customary to pass the material through more than one bath to produce the desired perfection of surface.

The acids used for pickling are commercial grades of hydrochloric and sulphuric acid. Until sulphuric acid was cheaply produced hydrochloric was used almost exclusively, but, except for special classes of work in which hydrochloric acid gives better results, it has now largely been superseded by sulphuric acid, a 60° grade (about 78 per cent pure) being in most general use. The strength of solution varies somewhat with the work to be done. The best solvent for the sesquioxide of iron is a solution consisting of 8 parts of sulphuric acid and 3 parts of water. A much weaker liquor is used in pickling, however, a 10 per cent solution of the 60° acid being a common strength for making up the fresh pickling bath.

Circulation is a primary requisite of good pickling. Were the material allowed to lie in a heap in the acid, some parts would be more thoroughly cleaned than others, the surface would become pitted, and the material would be seriously damaged in value. To avoid such results a rapid circulation of the liquid or a movement of the material pickled is necessary. This is customarily accomplished by machinery which automatically alternately thrusts the material into and draws it from the bath or which forces the liquid around the material by a plunger. The pickling solution is kept at a temperature ranging from 140° F. to a little more than 212° F. in order to increase the activity of the acid. This is usually done by forcing steam into the bath from open pipes.

At the Shelby Steel Tube Works circulation and heating are accomplished by closed steam pipes of acid-proof material laid in the bottom of each tub. The liquor is thus heated to a state of violent ebullition and an eminently satisfactory circulation obtained and very rapid and thorough pickling made possible.

As previously stated, the fresh pickling bath contains about 10 per cent of acid. As the process of pickling continues, the per cent of acid becomes less and less because of the combination of acid with iron to form iron sulphates. More acid is therefore added in a continuous stream or by charges in order to keep the bath working

actively. Finally, when the liquor contains about 15 per cent of iron sulphates and 2 per cent of acid it is discarded as useless and is generally discharged into the most convenient stream.

This forms waste 1, the first waste from the process. It is to be noted that the waste liquor or "spent pickle" from any one plant will be of fairly uniform consistency and is disposed of in charges, usually once or twice a day.

After pickling, the iron or steel material is passed through a rinse tub in order to free it from an excess of acid. Were it not rinsed the acid would continue to eat the material and would soon coat it with rust. The rinse tubs are usually similar to the pickling tubs in size and shape. A continuous stream of water passes through them, the discharge pipe leading to sewer or stream. This rinse water, of course, takes up a considerable quantity of iron and acid from the material pickled. It forms waste 2, the second waste from the process.

After it is rinsed the material to be coated is passed directly through the galvanizing, tinning, or other coating process, or it may first be subjected to a bath in very dilute hydrochloric acid to give a still better surface for coating. The waste from this last bath is usually inconsiderable in comparison with the others and passes out with the rinse water, waste 2. In the tube works, after pickling, the tubing is oiled in "dope" tubs similar to the pickling tubs. This process gives a little waste oil, which passes out with waste 2, but is not sufficient in quantity to merit special notice.

CHARACTER OF LIQUORS AT SHELBY.

In March, 1905, the writer visited the pickling plant at the Shelby Steel Tube Company and had samples of the various liquors collected. These samples were taken, and quantities of liquors, etc., were estimated or taken from the records of the company, by its employees. They can not, therefore, be vouched for by the writer. This is especially to be regretted, since later investigations upon stream and sewage show the presence of very much more acid-iron waste than the figures on wastes obtained from the company would lead one to expect. The officials of the company, however, appeared to be acting in good faith. Because of a disagreement between figures given for acid used and compounds of acid in wastes 1 and 2, corroborated by the writer's personal investigations in another pickling plant, it is believed that there is a large amount of drainage from pickled material and leakage from tubs, vats, etc., which passes out with these wastes, but is not taken into account in the measurements and does not influence the character of the samples taken. The writer therefore accepts without question all the figures furnished by the company. It is obvious, however, that in any plan to prevent

stream pollution, such drainage and leakage should be carefully collected and treated with waste 1 instead of being allowed to combine with waste 2, as it undoubtedly does in most plants. Being an unknown quantity, except from inference, it is not further considered in this report.

The following table shows the results of analyses made of samples collected March 29, 1905:

Results of analyses of pickling-process liquors.

[Parts per million.]

	Shelby city water influent to rinse tubs.	Effluent of rinse tubs.	Pickling liquor at end of first day.	Pickling liquor at end of second day.
Sample number	28	29	30	31
Acidity (H_2SO_4)	a 226	260	110,600	26,700
Sulphuric acid as SO_3	302	2,184	158,700	100,400
Iron as Fe	036	1,388	50,400	57,300
Gallons per day	9,550	9,550	1,230	1,230

a Alkalinity in terms of H_2SO_4.

Samples 28 and 29, being from continuous flows, are hourly composite samples, showing average composition for the working day. It is the custom to begin each day with three tubs of fresh pickling solution. At the end of the day these still contain active acid. They are retained, therefore, and used the following day for pickling the rougher material. At the end of the second day they are emptied. Each day, therefore, three tubs are filled and three emptied, six tubs being used in all.

Sample 30 is composed of equal parts from tubs filled on the morning of March 29, and sample 31 of equal parts from tubs filled the previous day. Both samples were taken after the pickling for March 29 had been completed. Sample 31, therefore, is "spent pickle," to be emptied from the tubs, and may be taken as the residual liquor from one day's pickling, really representing the heavy work of March 28 and the light work of March 29 combined.

Sample 30 is the residual liquor from the heavy work of March 29 and was used for the light work on March 30 for further neutralization of the acid.

On March 28, 6,300 pounds of 60° sulphuric acid were used in pickling, and on March 29 the amount required was 6,400 pounds. We may take, therefore, 6,350 pounds of acid as the quantity affecting the analyses shown in the table. This amount of 60° acid contains an equivalent of 4,030 pounds of SO_3.

From the report of the sulphuric acid industry appearing in the Twelfth United States Census, the average value of 60° acid is $14.47 per ton, or $22.75 per ton of SO_3 content.

RINSE WATER.

At Shelby the rinse water is now discharged into the sewers. A comparison of results on samples 28 and 29 shows that the 9,550 gallons of rinse water received from the material rinsed 150 pounds SO_3.

Of the SO_3 thus lost little is in the free state, that which has not already combined with the iron or has not been neutralized by the alkaline water being only a small portion of the whole. This loss represents 5.7 per cent of the acid used, or $1.34 a day. The solution is made too dilute to admit of economical recovery of any compound it contains. Its effect upon the sewage is of interest. Let us assume that the sewage would have, normally, the same iron content and alkalinity as the city water (sample No. 28 in table). The flow of sewage during the working day is about 150,000 gallons, say 15 times the amount of rinse water. The alkalinity would therefore be decreased by about one-sixteenth the acidity of the rinse water, or 16 parts per million, leaving it with an alkalinity of 210 parts per million, approximately. This effect is inconsiderable. The iron content would be increased by one-sixteenth the iron content of the rinse water, or 87 parts per million. There is no reason to suppose that this amount would affect injuriously the operation of the sewage-disposal works.

It appears, therefore, that the rinse water might safely be added to the city sewage without fear of nuisance. While it is far too dilute for the economical recovery of iron or acid in any form, the iron might readily be reduced to an insignificant amount by precipitation before it is allowed to enter the city sewers. This could best be done, theoretically, by the use, daily, of 100 pounds of NH_3 in the form of ammonia water, a small basin being provided for sedimentation. Satisfactory results could also be obtained by the use of 165 pounds CaO in the form of lime water. The cost would approximate 65 cents a day for precipitant. The precipitated lime and iron would be of some value to paint manufacturers.

SPENT PICKLING LIQUOR.

In the 1,230 gallons of pickling liquor discarded at the close of the day, 1,230 pounds of SO_3 are found, representing a value of $14 in acid used. This exists chiefly as ferrous sulphate, some ferric sulphate and about 2.5 per cent of free sulphuric acid being also present.

About 2,650 pounds of SO_3, or nearly two-thirds (more exactly, 65.8 per cent) of the active principle in the acid used, is lost in the pickling tubs. Although a part of this passes off as fumes, it is presumed that nearly all this loss is due to splashing and leakage from the tubs and drainage from the pickled material, and that most of the lost pickling liquor passes to the sewer together with the effluent of

the rinse tubs. The spent pickling liquor discarded at the close of each working day is at the present time passed through a copperas-recovery plant.

COPPERAS PLANT AT SHELBY.

With the twofold idea of preventing the discharge of the liquor into the stream and, if possible, of adding to the economy of pickling operations, a plant for the recovery of copperas from spent pickle was installed during August, 1904, at the works of the Shelby Steel Tube Company.

This plant is exceedingly simple in construction and operation. The spent pickle is drained by gravity into a lead-lined wooden receiving or storage tank of rectangular cross section, having a capacity of about 6,000 gallons—sufficient to accommodate the spent pickle from four days' work. From the storage tank the liquor is drawn by charges into an evaporator for concentration. The evaporator is a wooden tub of rectangular plan and trapezoidal elevation having a capacity of a little more than 2,000 gallons. The tub is lined with one-eighth inch lead and heated by a steam coil. It is provided with a wooden hood and a draft for carrying off the vapor. A much more economical evaporator, though more expensive in first cost, could be used.

Iron or steel turnings are introduced into the evaporator to neutralize the free acid and to reduce ferric to ferrous sulphate. The liquor is concentrated to about 45° Baumé (sp. gr. 1.453; Twaddell, 90.6°) and then drawn off into wooden crystallization tubs. These tubs are rectangular in cross section and have a capacity of about 675 gallons each. To assist in the crystallization and to provide a support for the crystals, wooden strips are hung in the tubs. The dependent crystals are gathered, drained, and barreled for shipping. The mother liquor, together with the more impure crystalline copperas from the sides and bottom of the tubs, is pumped back by hand to the storage tank or the evaporator. Occasionally such matter is discharged into the stream with wash water from the tubs to dispose of accumulated impurities.

In the original plant three crystallization tubs were used, but three more were added in the summer of 1905, making six in all.

Analysis of the crystals produced gave the following results in per cent: Acidity as H_2SO_4, 0.2; sulphuric acid as SO_3, 27.5; iron as Fe, 18.9. This approximates the formula $FeSO_4.7H_2O$ for ferrous sulphate crystals, but indicates the presence of small amounts of ferric sulphate and free acid.

Average figures for several months show that the copperas produced is, by weight, 50 per cent of the acid used in pickling. For the 6,350 pounds of acid used (average of March 28 and 29), therefore, a

product of 3,175 pounds of copperas would be obtained, having a content of 875 pounds SO_3. This is 21.7 per cent of the SO_3 in the acid used for pickling, or 71.1 per cent of the SO_3 in the spent pickle.

There is therefore a loss—presumably taking place by leakage in the evaporator, storage tank, and crystallization tubs—of 8.8 per cent of the active principle of the acid used for pickling, or 28.9 per cent of the amount of such principle present in the spent pickle.

The estimated disposal of the SO_3, assuming an average daily use of 5,000 pounds of acid, may be summed up as follows:

Losses and recovery of sulphuric acid at Shelby Steel Tube Company.

	Per cent.	Pounds per day.		Value as 60° acid.
		Acid.	SO_3.	
Loss in rinse water	3.7	185	144	$1.34
Loss in pickling tubs	65.8	3,290	2,566	23.80
Loss in copperas plant	8.8	440	343	3.18
Recovered in copperas	21.7	1,085	847	7.85
Total	100.0	5,000	3,900	36.17

Original estimates on cost of recovery per ton of product were as follows:

Coal, at $2.25 per ton	$1.08
Iron turnings, at $13 per ton	.89
Barrels, etc., for shipping	1.90
Total	3.87

It is thought that $2 will more nearly approximate the actual cost of fuel for evaporation with the evaporator used, although, owing to the complication of heating arrangements, no exact figures are obtainable.

Accepting the other items as correct and adding $1 per ton for labor and $0.50 per ton as a 10 per cent annual depreciation upon a plant valued at $2,000, we have, for the production of one ton of copperas, the following figures:

Average value of copperas (Twelfth U. S. Census)		$9.64
Fuel, at $2.25 per ton	$2.00	
Iron turnings, at $13 per ton	.89	
Miscellaneous supplies	1.90	
Depreciation	.50	
Labor	1.00	
		6.29
Profit		3.35

This is a very liberal estimate of costs, and will, without doubt, be sufficient to more than cover the actual conditions at Shelby. Were the plant arranged to save the liquor now lost and a better evaporator used, a much better showing could be made. It must be considered that the advantageous arrangement of the plant for gravity flow contributes in some measure to the low cost of the product. Were pumping required, the cost would not in any case be more than $6.64 per

ton, leaving $3 per ton as a low estimate of profit under extremely adverse conditions.

With a capital of $2,500 and a yearly product of 400 tons of copperas, the foregoing figures would show an annual profit of $1,340, or 53.6 per cent upon the capital invested. The margin of profit, with the present price of copperas, is large enough to permit the application of the method to any plant of size sufficient to create a nuisance by stream pollution.

OTHER PROCESSES FOR DISPOSAL OF PICKLING LIQUOR.

Several other processes for the disposal of sulphuric-acid pickle have been tried experimentally and a few have been applied on a commercial scale. The most prominent of these and their results are tabulated below:

Process.	Result.
Electrolytic regeneration of acid	Expensive.
Recovery of basic ferric sulphate and acid by aeration	Expensive.
Recovery of "sugar copperas"	Practicable.
Chemical precipitation	Expensive.

So far as known, recovery of copperas in large crystals and as "sugar copperas" are the only processes that will pay for the cost of disposal of the spent pickle from sulphuric acid.

For spent pickle from hydrochloric acid containing iron chlorides a cycle of regeneration has been perfected in England by Thomas Turner. The method is described at some length by Naylor in Trades Waste, pages 262–263. In brief, the pickle is fed into a reverberating furnace; iron oxide is retained and hydrochloric acid passes over with the fire products and is condensed in ordinary muriatic towers. The cost of 75 per cent acid recovered is stated at about $2. In this country it would doubtless be somewhat higher.

SUMMARY.

The investigations at Shelby, Ohio, have brought out the following points:

1. Stream pollution by acid-iron wastes has been taking place at Shelby for about fifteen years, to the annoyance of riparian residents below the city for a distance of 12 miles. Complaints against this pollution (which may be defined as the entire waste of pickling liquors in which one pound of 60° sulphuric acid is used to each 175 gallons per second of dry-weather flow in the stream) culminated in 1901 in a series of suits against the corporation responsible for the pollution, resulting in awards of damages in favor of residents along the stream living from 3 to 7 miles below the point of pollution.

2. Conditions along the stream were greatly bettered by the passage of the waste through the city sewage-purification works (consisting of a sludge basin, shallow five-day sedimentation reservoirs, and shallow cinder and gravel filters), diluted by from 10 to 20 times its volume of a weak domestic sewage.

3. The effect of the acid-iron sewage upon the sewage purification plant was to fill basin and reservoirs rapidly and thus decrease their efficiency, to destroy the working value of the filter beds in a comparatively short time, and to increase great y the care requisite for the proper maintenance of the plant. Bacterial action was seriously interfered with, the action of the early processes of the plant upon organic matter was diminished, and the effluent was rendered obnoxious by reason of a high content of iron sulphate. Odors about the plant and danger from pathogenic bacteria in the effluent were decreased by the acid-iron character of the sewage.

4. The treatment of pickling waste in a plant for the production of crystal copperas, one-fifth of the acid used being so recovered, reduces the objectionable features of the sewage by about 60 per cent, and is therefore of great value as a means of preventing stream pollution by such wastes.

The copperas-recovery process is the best method known for treatment of sulphuric-acid pickling liquors, is attended with a large per cent of profit, and is applicable to pickling plants of all sizes. Such a plant, properly arranged, will entirely obviate stream pollution by "waste pickle."

5. Rinse water from the pickling process, not including leakage and splashage from the pickling tubs, can, in general, be discharged into the sewerage system of a town or into a stream without detrimental consequences, but it will produce a discoloration of the water unless the dilution is very great. Although such waste does not seriously affect the uses of a stream, it may be rendered entirely unobjectionable at a trifling cost by precipitation with lime or ammonia, and such treatment is advised.

6. Of the acid used in pickling at Shelby, only 21.7 per cent is recovered in the copperas product. Of the remaining 78.3 per cent, 8.8 per cent is lost in the copperas plant, 65.8 per cent is lost in the pickling process, and 3.7 per cent passes into the city sewerage system as rinse water. Of the 74.6 per cent not definitely accounted for by the officials of the company, a part passes off as fumes from the pickling tubs; some is known to be discharged directly into the streams as washings from tubs, and the remainder apparently enters the stream direct or by way of the sewers, presumably as leakage.

This "lost" acid is the cause of the present pollution at Shelby. By designing the plant so that this waste may be recovered as copperas, stream pollution can be practically obviated and the economic value of the plant greatly enhanced.

7. The present pollution at Shelby makes the stream waters red and turbid, seriously damages them for general use, and renders them deleterious to fish life for a total of not more than 2 miles. No other damaging effects were found except an increase in the permanent hardness of the water, by which it becomes less suitable for boiler and for domestic use.

ASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 186.]

The serial publications of the United States Geological Survey consist of (1) nual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) neral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas United States—folios and separate sheets thereof, (8) Geologic Atlas of United tes—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publica- n; the others are distributed free. A circular giving complete lists can be had on plication.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they n be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress, r distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, . C., from whom they can be had at practically cost.
4. Copies of all Government publications are furnished to the principal public braries in the large cities thruout the United States, where they can be consulted y those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of ubjects, and the total number issued is large. They have therefore been classified nto the following series: A, Economic geology; B, Descriptive geology; C, System- tic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investi- gations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the fourteenth in Series L, the complete list of which follows (WS= Water-Supply Paper):

SERIES L, QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)
WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)
WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.
WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp., 15 pls.
WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.
WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.
WS 113. Strawboard and oil wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.
WS 121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.
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WS 152. A review of the laws forbidding pollution of inland waters in the United States, second edition, by E. B. Goodell. 1905. 149 pp.
WS 161. Quality of water in upper Ohio River basin and at Erie, Pa., by S. J. Lewis. 1906. 114 pp., 6 pls.
WS 179. Prevention of stream pollution by distillery refuse, based on investigations at Lynchburg, Ohio, by Herman Stabler. 1906. 34 pp., 1 pl.
WS 185. Investigations on the purification of Boston sewage, by C.-E. A. Winslow and Earle B. Phelps, 1906. — pp.
WS 186. Stream pollution by acid-iron wastes, a report based on investigations made at Shelby, Ohio, by Herman Stabler. 1906. 36 pp., 1 pl.

Correspondence should be addrest to

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Water-Supply and Irrigation Paper No. 187 Series M, General Hydrographic Investigations, 19

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

DETERMINATION OF STREAM FLOW DURING THE FROZEN SEASON

BY

H. K. BARROWS AND ROBERT E. HORTON

WASHINGTON
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1907

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DETERMINATION OF STREAM FLOW DURING THE FROZEN SEASON.

By H. K. Barrows and R. E. Horton.

IMPORTANCE OF WINTER RECORDS OF STREAM FLOW.

Estimates of the flow of rivers are now being made by the United States Geological Survey in all parts of the country. To a great extent these are based on daily gage readings and numerous current-meter measurements.

In the northern and central parts of the United States the streams may be closed by a more or less permanent ice cover for a considerable portion of the year. This period varies from nearly five months in the extreme north to a few weeks or less in the Central and Atlantic States.

The methods in use for estimating flow under open-channel conditions have become well defined, and the limits of accuracy are known to be reasonable. On the other hand, the laws governing the flow of rivers that are frozen over have been but little investigated, and methods for estimating the flow under such conditions have not been formulated. Moreover, in winter the measurement of precipitation is more difficult, and available data of this kind are much less accurate than in summer. Finally, there is not even an approximate relation between the snowfall and the stream flow, so that the failure to obtain winter records of flow at a gaging station means a considerable percentage of uncertainty as to the total run-off as well as to its distribution.

In the Northern States droughts are apt to occur in the late summer or fall and during the winter. At times this condition of drought may be nearly or quite continuous between these two periods, with its culmination in January or February. If there is no melting of snow during the winter, the inflow to streams that freeze is chiefly derived from springs, ground water, and lake storage, and in a long, cold winter, especially if it succeeds a period of low water, the minimum flow for the year may be reached and continue for some time. Estimates of flow, therefore, to be of conclusive value on streams utilized for water power, must embrace these winter periods of low water.

METHODS OF GAGING STREAMS DURING THE OPEN SEASON.

GENERAL STATEMENT.

The methods of stream gaging in common use by the United Stat Geological Survey contemplate especially the determination of di charge when streams are free from ice at or near the gaging station One object of the present paper is to determine what modificatio of these methods are necessary to secure good results when the strean are ice covered. With this in view a brief description of open-wat methods is given below.

In general a record of the fluctuations in stage is obtained by dai reading a gage or gages. Various methods are used to obtain a ra ing of the stream so that the discharge in second-feet can be determin from the gage readings. Three principal methods of rating are use—(1) the weir method, in which a weir or dam is used and the flo is computed for a given gage height; (2) the velocity method, which a series of current-meter or float gagings are made at a giv cross section and a discharge rating curve is obtained for that cro section; (3) the slope method, in which observations are made of t mean cross section and surface slope in a stretch of the river, and t velocity is computed by the Chezy-Kutter formula, $V = C\sqrt{RS}$, suitable value being assumed for the coefficient C.

WEIR METHOD.

Weirs of standard type with sharp crest can be used on sm streams only, on account of the cost of installation and liability injury. Where practicable, they offer the best facilities for dete mining the flow. The flow at dam stations is usually divided—pa going over the dam, part through the wheels, and part through b channels. A weir formula with modified coefficient is used to cor pute the flow over the dam. The wheels are used as meters, a reco being kept of gate openings, head, etc. Flow through by-channe which at many dams occurs only at intervals, is computed by the u of weirs, orifices, etc. The sum of these components is the tot discharge of the river at the section. The general methods used stations of this character are fully described in Water-Supply Pap No. 150.

VELOCITY METHOD.

The determination of the rate of flow past a certain section of stream at a given time is termed a "discharge measurement." Th rate is the product of two factors—the mean velocity and the area cross section. The mean velocity is a function of surface slop wetted perimeter, roughness of bed, and the channel conditions a above, and below the gage section. In this method it is assum

that the stream bed is constant in form and position and that the mean velocity at any given stage will always be the same. Therefore a rating curve may be obtained by plotting the results of a sufficient number of discharge measurements at different stages. In making the measurements an arbitrary number of points, known as "measuring points," are laid off on a line perpendicular to the thread of the stream, and the velocity and depth are observed. These points are usually at regular intervals from 2 to 20 feet apart, depending on the size and condition of the stream. The current meter is commonly used for obtaining velocities, although in a few cases rod or tube floats are utilized for this purpose. The area is thus divided into small sections in which the velocity is observed and the discharge computed, and the sum of the values for these sections gives the total area and discharge. If a sufficient number of discharge measurements are made at different stages, a rating table can be constructed that will show the discharge at any stage of the stream. The methods used in selecting current-meter stations and in collecting data are fully described in Water-Supply Papers Nos. 94 and 95.

SLOPE METHOD.

The results obtained from the slope method are in general only roughly approximate, owing to the difficulty in obtaining accurate data and the uncertainty of the value to be used for n in Kutter's formula. The most common use of this method is in estimating flood discharge of streams when the only data available are the cross sections, the surface slope as shown by marks along the bank, and a knowledge of the general conditions.

Throughout this paper velocities are expressed in feet per second, gage heights in feet, and the volume of flow of streams in cubic feet per second, or second-feet.

CONDITIONS DURING THE WINTER SEASON.

FACTORS AFFECTING ICE FORMATION.

Rarely, if ever, in this country does a stream of any size freeze over throughout its whole length, there being usually short stretches that remain more or less open. Two important factors govern the formation of ice on streams—(1) the climatic or general temperature conditions; (2) the size and character of the stream and the conditions affecting its flow.

In California, Washington, and Oregon, and south of latitude 37°, with the exception of perhaps a portion of northern New Mexico and Arizona in the Rocky Mountain district, the rivers do not in general freeze over sufficiently to affect records of flow or to occasion any change in methods from those of the open season.

In the most general sense, the character of the bed and banks of a stream depends on its slope and the materials over which it flows. A stream will not freeze over unless the water has a temperature as low as 32° F. and is comparatively still. If the water is greatly agitated, needle ice will be formed instead of an ice cover. This tendency to form needle ice always exists at rapids, particularly if the stream bed is very rough. If the cold is extreme and long continued even such places may eventually become frozen—the freezing starting at the water's edge or around rocks and piers, where the velocity is lower, and extending toward the center of the stream. The result, however, is not in any case a smooth ice cover, but a piling up of very rough or "honeycombed" ice which may be partly supported by rocks.

Where dams have been constructed there is usually above the dam more or less pondage and a great diminution in velocity, so that such portions of a river freeze over very readily. Below the dam quick water is frequently left, and conditions may be the same as at rapids.

Any special conditions tending to raise the temperature of the water may have a marked effect on the time or manner of freezing over of a portion of a stream. Near the outlets of lakes or in streams fed by springs or ground water there may be a sufficient inflow of water having a temperature considerably above 32° F. to prevent wholly or at least for some time the formation of an ice cover. Such conditions are also potent in assisting the rapid wearing away of the under surface of the ice and, in general, they result in very unstable conditions as regards ice cover. The temperature of springs is ordinarily about equal to the average annual temperature of the locality, which is for the Northern States 40° to 50° F.

CLASSIFICATION OF WINTER CONDITIONS.

It is evident that streams of any considerable length can not be classified as a whole with regard to ice formation or winter conditions, for the reason that very diverse conditions may occur at different parts of the same stream. The conditions on short stretches of streams, and particularly on such stretches as need to be considered in selecting current-meter stations, may be classified as follows:

Classification of winter conditions at current-meter stations.

(1) Smooth, permanent ice cover.
(2) Tendency for anchor or needle ice to accumulate underneath ice cover.
(3) Unstable ice cover, due to—
    (*a*) Effect of warmer inflow from lakes or tributary streams.
    (*b*) Effect of inflow of ground water.
    (*c*) Effect of warm currents due to artificial causes, such as factory waste, etc.
    (*d*) Concentrated quick water and wearing away due to friction.
    (*e*) Considerable fluctuation in stage occasioned by winter freshets.
(4) Rough ice cover and piling up of ice due to quick water and rough bed.

(5) Tendency for ice jams to occur, with consequent backwater, etc.
(6) Streams that remain open altogether or freeze over thinly for short times, owing to—
  (a) Extremes of conditions as noted under (3).
  (b) High temperature, mainly in the southern portion of the area, subject to ice conditions in winter.

The above classification is intended for the ordinary winter. The winter of 1904–5 was much colder than the average, and many streams remained frozen over in places where ordinarily there would not be permanent ice. On the other hand, the winter of 1905–6 was remarkably mild, and ice was carried away by freshets at many points where this very rarely happens. A gaging station, then, can be only approximately fixed in any of the above classes.

The following tables summarize the winter conditions at 179 current-meter stations and 25 dam stations:

Summary of winter conditions at current meter stations.

Class.	New England.	New York and lower Michigan.	Atlantic States.	Central States.
(1) Smooth, permanent ice cover	11	11	13	35
(2) Tendency for anchor and needle ice to accumulate.	4	5	2	(a)
(3) Unstable ice cover	10	3	21	9
(4) Rough ice cover and piling up	7	3	6	(a)
(5) Tendency for ice jams	1	1	8	(a)
(6) Remain open	5	10	7	7
	38	33	57	51

[a] Not reported in detail.

Of the 179 stations considered 29 remain unfrozen thruout the winter, and at these stream flow can be estimated in the same manner as during the open season. Smooth, permanent ice cover is found at 70 stations. The remaining 80 stations have miscellaneous conditions, all of which are probably unfavorable for estimating winter flow.

Summary of winter conditions at stations at dams.

Good conditions for estimates, crest unobstructed, ice cut away, or water mostly used by wheels	13
Poor conditions for estimates, crest seriously obstructed	12
	25

DURATION OF ICE SEASON.

The following table gives the usual duration of ice cover in different areas where the streams freeze during the winter.

Duration of ice cover, by areas.

Locality.	Date of closing in.	Date of breaking up.	Time frozen.
			Months.
Northern Maine	November 15–30	March 15–April 15	3½–5
Northern Michigan	December 1–30	March 1–15	2 –3½
Lower New England	December 15–January 1	February 15–March 15	1½–3
New York	December 1–15	March 15–31	3 –4
Pennsylvania	January 1–15	March 1–15	1½–2½
Illinois	December 15–January 15	February 15–March 1	1 –2½
North Dakota	November 15–30	March 15–31	3½–4½

A large amount of information relating to the duration of the ice season, especially with regard to lakes and navigable streams, was published in the report of the United States Deep Waterways Commission.[a] A few of the results for rivers there given are compiled in the following table:

Duration of ice cover on northern streams.

River.	Locality.	Length of record.	Average date of—		Time closed.
			Closing.	Opening.	
		Years.			*Days.*
Connecticut	Hartford, Conn	42	Dec. 12	Mar. 12	90
Do	Turners Falls, Mass	12	Dec. 9	Mar. 16	97
Hudson	Albany, N. Y	87	Dec. 15	Mar. 20	95
Illinois	Peoria, Ill	53	Dec. 17	Feb. 21	66
Merrimac	Amoskeag, N. H	18	Nov. 28	Mar. 19	111
Mississippi	Davenport, Iowa	25	Dec. 12	Mar. 19	97
Do	St. Louis, Mo	31	Dec. 19	Jan. 20	32
Missouri	Bismarck, N. Dak	24	Nov. 25	Mar. 31	126
Do	Fort Buford, N. Dak	15	Nov. 15	Apr. 13	151
Ohio	Cincinnati, Ohio	39	Jan. 15	Jan. 25	10

CHANGE IN THICKNESS OF ICE.

After a stream becomes frozen over, the thickness of the ice usually increases rapidly, reaching a maximum generally by midwinter and then remaining nearly constant until shortly before the open-water season begins. As a rule there is some melting and thinning of the ice before it goes out, but a heavy early spring freshet may carry out ice at its maximum thickness.

The following table shows the ice thickness at intervals through the winter at two fairly typical gaging stations.

Thickness of ice on Connecticut River at Orford, N. H., and Esopus Creek at Kingston, N. Y.

Date.	Connecticut River at Orford, N. H.			Esopus Creek at Kingston, N. Y.		
	1903–4.	1904–5.	1905–6.	1903–4.	1904–5.	1905–
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet*
November 15		0	0			
December 1		.3	.1	0	0	0
December 15	0	.7	0	0	.4	
January 1		1.3	0	.5	.65	
January 15	1.7	1.5	.7	.95	.6	
February 1	1.85	1.7	0	1.1	1.25	
February 15	1.9	2.1	1.05	1.25	1.5	
March 1	2.1	2.2	1.15	1.25	1.6	
March 15	2.	2.1	1.1	.6	.7	
March 30	0	0	0	a 0	a 0	a 0

[a] March 31.

SURFACE, ANCHOR, AND NEEDLE ICE.

The three following forms of ice occur in streams and each of them affects the flow in a different way: (1) Cake, border, or surface ice; (2) needle ice, or "frazil," so called from the French word signifying

[a] House Doc. 192, 54th Cong., 2d sess.

"forge cinders," which are suggested by its dull, slushy appearance; (3) anchor ice, which closely resembles needle ice, but which is formed in a different manner.

Surface ice is formed when the temperature of a quiet body of water becomes 32° F. As the maximum density of water occurs at 39.1°, the temperature of a quiet body of water that is cooled from the surface will gradually increase from the surface downward after a general water temperature of 39.1° has been reached. Surface ice probably always begins to form at the shore or at the borders of solid objects and is extended by spicules shooting out and forming a network, the process being analogous to the growth of crystals in a saturated solution except that ice is formed at the surface only. The surface layer of ice gradually increases in thickness and continues to grow as long as the air temperature is below 32° F. The rate of such increase varies with the temperature and other atmospheric conditions affecting heat radiation. The thickness of the ice layer increases in nearly direct proportion to the square root of the time. Surface ice also forms over smooth-flowing water, but as the velocity and roughness of the current are increased a condition is soon reached where the projecting ice needles are broken off as fast as they are foremd.

It is obvious that the surface temperature of a stream passing over rapids where surface ice can not form would often fall below 32° F. if a portion of the water were not converted into ice in some manner and enough latent heat released to maintain the temperature constantly at 32°. It is well known that perfectly quiet water can be cooled below 32° F. without the formation of ice, apparently because the necessary nuclei and other conditions to start ice formation are not present. If, however, the slightest motion occurs, the water molecules are enabled to assume the arrangement necessary to crystallization and the water becomes filled with ice spicules.

Elaborate experiments by Prof. Howard T. Barnes by means of an electrical-resistance thermometer indicate that flowing water in a stream can not be cooled more than one one-hundredth of a degree below the freezing temperature without the formation of ice. The ice spicules that form in agitated water vary in character with the variations in the rate of their formation. Elongated needles, cubical crystals, and broad, thin plates have been observed under different conditions. Apparently the stream may be filled with needle ice formed in the manner described without the flow being affected in any considerable degree. If, however, the needle ice is carried underneath the layer of surface ice, it forms an effective obstruction.

Observations in St. Lawrence River indicate that masses of needle ice may travel under the surface ice for several miles. There is undoubtedly some flow through these masses, but the velocity is very

slight. It has not been found possible to measure the flow through ice with the current meter. The existence of flow is, however, cated by the presence of impurities in the ice. A striking illustr of this flow is also given in fig. 1, which shows two cross sectic Chemung River. At the upper section the channel underneat surface ice was almost completely blocked by needle ice, while a lower section, 200 feet downstream, there was but little needl

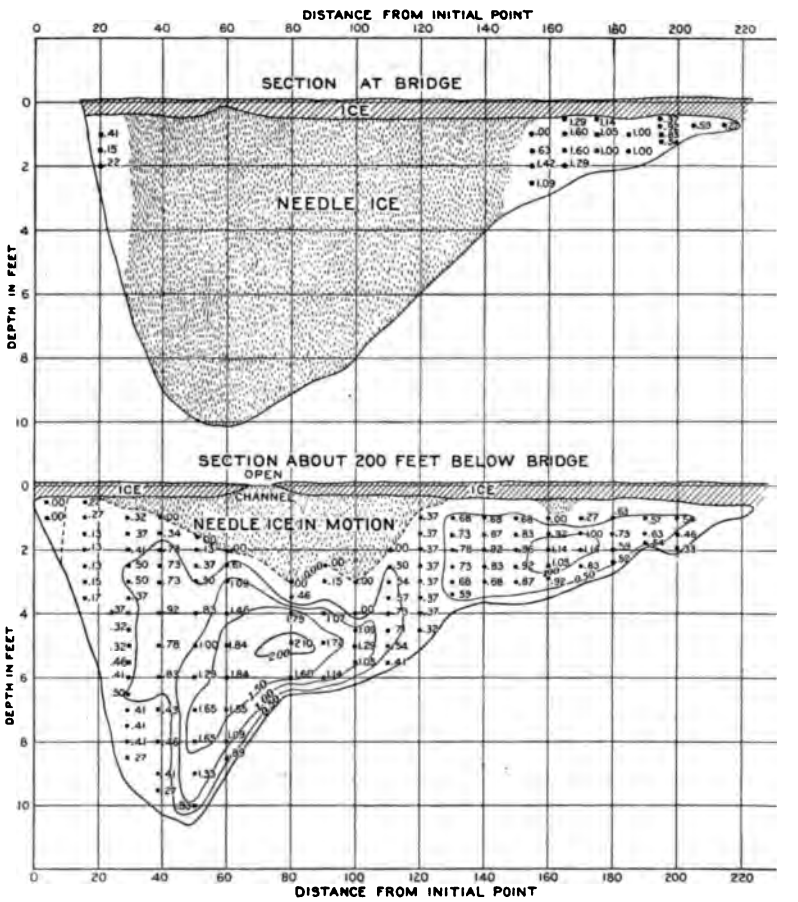

FIG. 1.—Cross sections of Chemung River at Chemung, N. Y., showing effect of needle ic

yet the observed velocities at the lower section were so great indicate that considerable flow through the masses of needle ice have taken place.

Gage readings or attempts to estimate the winter flow of str at cross sections affected by needle ice are apparently wort Although the general features of ice formation in a given locality w the same from year to year, a consideration of the conditions of ne

ice formation shows that the differences will be sufficient to produce in effect a constantly changing regimen. The formation of needle ice, like that of surface or anchor ice, is due chiefly to radiation of heat from the water mass. Needle ice never forms underneath surface ice and is most frequently formed on cold, clear nights, when the heat lost by radiation is most greatly in excess of that received at the earth's surface. Professor Barnes states that the margin between the disintegration and the formation of the ice is exceedingly narrow, amounting to only a few thousandths of a degree change of temperature, the radiation and the absorption of the sun's rays by water being controlling factors.

Snow falling on the surface of a stream becomes water-logged and forms a slush resembling floating needle ice. Snow crystals probably often form the nucleus of masses of needle ice, but the presence of snow is not an essential or important condition for the occurrence of such ice, as is sometimes supposed.

Anchor ice is sometimes formed when stones or other objects in a stream are cooled by radiation to 32° F. It is a crystalline growth similar to needle ice and having the same density. It remains attached to the objects upon which it is formed as long as their surface temperature is below 32°. Like needle ice, it forms most readily when the difference between radiation and absorption is a maximum. Apparently it never forms underneath surface ice; but whenever the relative loss by radiation is decreased, as, for instance, on a cloudy day, it may become detached and rise to the surface, carrying with it stones or other objects. It affects the regimen of streams chiefly by forming obstructions in portions of the channels that do not freeze over, thereby causing back water, or by rising and floating underneath the surface ice, as needle ice often does. Anchor ice does not ordinarily form in streams with earth beds and apparently forms more extensively on dark-colored rocks, radiation from dark objects being greater than from light ones.[a]

RANGE OF WINTER GAGE HEIGHTS.

Data regarding extremes of winter gage heights are given in connection with station descriptions (pp. 26–38). In general, winter freshets are uncommon in the northern portion of the area, in which the streams freeze and the range in stage is small, but the liability of their occurrence increases rapidly to the south. They are, however, usually not of long duration, and are not serious factors in winter

[a] Rept. Commission of Engineers on Floods, Montreal, 1890. Henshaw, Geo. H. Frazil ice: Trans. Canadian Soc. Civil Eng. vol. 1, pp. 1-23. Barnes, Howard T. Formation and agglomeration of frazil and anchor ice: Canadian Engineer, May, 1897, pp. 6-10; Formation of anchor ice and precise temperature measurements: Trans. Am. Soc. Mech. Eng., 1905. Horton, R. E., Anchor ice and frazi : Paper Trade Journal, December 24, 1903.

estimates unless they are of sufficient size to cause the ice to break up and go out more or less completely, when the conditions of flow may become entirely changed. As a rule the regimen of flow changes less in winter than during the open season.

FLOW OF STREAMS UNDER ICE COVER.

GENERAL CONSIDERATIONS.

In the Chezy formulas

$$Q = A\,V$$
$$V = C\sqrt{R\,S}$$

C is the coefficient dependent on the physical character of the stream bed and the hydraulic radius. The physical character enters into the determination of C in the form of a coefficient of roughness, n. The relation of n, R, and C, as deduced by Kutter, is as follows (for English units):

$$C = \frac{41.66 + \frac{1.811}{n} + \frac{0.00281}{S}}{1 + \left(41.66 + \frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

It will be seen that for a given slope and hydraulic radius the mean velocity of a stream is nearly proportional to $1 \div n$; that is, the velocity is inversely proportional to the roughness of the stream bed. The Chezy and Kutter formulas are empirical and in their application values of n determined from previous experiments are selected by judgment.

FRICTION DUE TO AIR AND ICE.

If V, R, and S are given, the value of n may be calculated from the Kutter formula. In such calculations for open-channel conditions the hydraulic radius is taken as the ratio of area of cross section to the wetted perimeter, not including the surface in contact with the air. It is probably true, however, that the mean velocity of a stream is usually less than it would be if there was no friction between water and air.

If the air-contact surface is replaced by a film of ice, then, in making a calculation of C or of the velocity, the entire wetted perimeter, including that portion of the boundary of the stream section in contact with ice, would naturally be included in calculating the hydraulic radius.

If the value of n is derived by considering the wetted perimeter as including the air and ice contacts as well as those of bed and banks, and if the frictional resistance of the water-ice contact is greater than

the frictional resistance of the water-air contact, then n will have a correspondingly greater value for conditions of ice cover than for those of open channel. In other words, the ice cover increases total friction by an amount representing the difference between air and ice resistance and not by an amount representing the total ice friction.

The ordinary friction of a stream bed may be considered as made up of two parts—(1) skin friction and (2) internal motion.

In most instances a film of water adheres to the surface of solid objects over which the water flows, and the skin friction between the water and these objects is essentially the same as that between two fluid surfaces. It is measured by the viscosity of the liquid, the energy absorbed probably being for the most part converted into heat.

If the stream bed is rough, the impact of the water creates swirls or eddies, in which a portion of the energy is converted into internal or vortex motion not useful in causing forward motion.

So far as known, no experiments have been made relative to the skin friction of a smooth ice surface. It may be assumed, however, to be about the same as for a smooth glass or planed-wood surface, especially the latter. A layer of water adheres to such a surface or is entrapped by the capillaries, so that the friction surface is essentially a layer of liquid particles, the conditions thus closely resembling those where water at 32° F. is in contact with ice.

The value for glass or planed-wood surfaces of n in Kutter's formula is given by various authorities as about 0.009, or from one-fourth to one-third the resistance due to an ordinary stream bed. When the under ice surface is rough, broken, tilted, or honeycombed, its impact resistance may become of the same or even greater relative importance than that of an earth or rock surface. It is presumable that cases are rare where the under surface of the ice cover is so free from irregularities as to give a value of n as low as those applying to glass or planed wood.

Occasionally a layer of needle ice of varying thickness floats under or accumulates on the lower surface of the ice cover. Such ice not only obstructs the flow through the portion of the cross section occupied, but also greatly increases the friction as compared with that of a smooth ice surface.

RELATIVE IMPORTANCE OF AIR AND ICE FRICTION.

As already pointed out, the actual increase in friction due to an ice cover is the difference between the ice friction and the air friction previous to the formation of the ice cover. Owing to the divergent opinions entertained as to the magnitude of air friction, it has been thought well to discuss the matter somewhat at length.

In the Chezy formula and in most other similar slope formulas it is assumed that all the resistance to the motion of the water proceeds from the stream bed. Humphreys and Abbot[a] found, however, that the position of the point of maximum velocity in vertical velocity curves on Mississippi River was controlled by the direction and velocity of the wind. They give the following expression:

$$d=(0.317+0.06f)\ D$$

In this formula D=depth in feet; d=depth of point of maximum velocity; f=relative wind velocity on a scale such that a calm=0 and a hurricane=10.

In deriving a formula for the mean velocity of streams in terms of the slope and hydraulic radius, Humphreys and Abbot assumed that the frictional resistance between the water and air contact surface was similar in nature and magnitude to the bed resistance. In their formula, accordingly, the hydraulic radius is expressed as follows:

$$R=\frac{A}{P+W}$$

In this formula A = area of cross section, P = wetted perimeter in earth, W = width of surface.

In discussing the results of Humphreys and Abbot's investigations the late James B. Francis made the following clear statement as to the effect of air friction:[b]

> When the air in contact with the surface of the water flowing in an open channel is moving in the same direction and with the same velocity as the surface of the water, it is clear that it can have no effect on the motion of the water; but such exact conformity in the motion of the air and water is uncommon; ordinarily the air has some motion relatively to that of the water and either retards or accelerates the velocity of the surface. That the air may produce a material effect on the scale of velocities is apparent from the following considerations.
>
> Let us suppose the surface of the water to move, relatively to the air, with the same velocity that the water at the bottom moves relatively to the bed; also that the inequalities of the surface of the water caused by the action of the air and those in the bed of the stream are alike; and suppose, also, that a sheet of water of uniform thickness, in contact with the bed, is at rest; we shall then have the water near the bottom moving over a bed of water and the water at the surface moving under a bed of air, and as both beds have the same inequalities, they will cause the same retardation in the velocity of the water, except as these beds, from the nature of the substances of which they are composed, offer more or less resistance. These resistances will be of the same nature as is experienced by a body moving in a resisting medium. According to well-known principles, the retardation in this case is as the square of the velocity of the moving body relatively to that of the medium and as the density of the medium. The density of the air is about $\frac{1}{815}$ of that of water; a body moving through the air with the same velocity will therefore be retarded $\frac{1}{815}$ as much as if it moved through water.

The above conclusions are confirmed by a comparison of the coefficients that have been determined experimentally for use in comput-

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[a] Physics and Hydraulics of Mississippi River, p. 305.

[b] Lowell Hydraulic Experiments, pp. 158–159.

; of pressure occasioned by the flowing of air and water through the form of expression adopted by Weisbach being used:

$$p = f \frac{l}{d} \frac{v^2}{2g}$$

iis formula p = loss of pressure in pounds per square inch; l = of pipe in feet; d = diameter of pipe in inches; v = mean velocity eet per second; f = coefficient of resistance to flow.

gh average values of the coefficient f, according to Weisbach's nents, may be taken as follows: For air, $f = 0.000160$; for $f = 0.104$, the relative friction loss for water being 650 times r air.

ems probable, then, that with still air the frictional effect of air er surface is but a small percentage of that due to stream bed, gh with a strong wind upstream the retardation of the filaments :r near the surface may be considerable.

VARIATION IN SLOPE DUE TO FREEZING.

n ordinary stream is made up of smooth-water reaches separ)y more or less pronounced rapids, and as the swiftest portf a stream freeze least readily, the freezing of a stream will

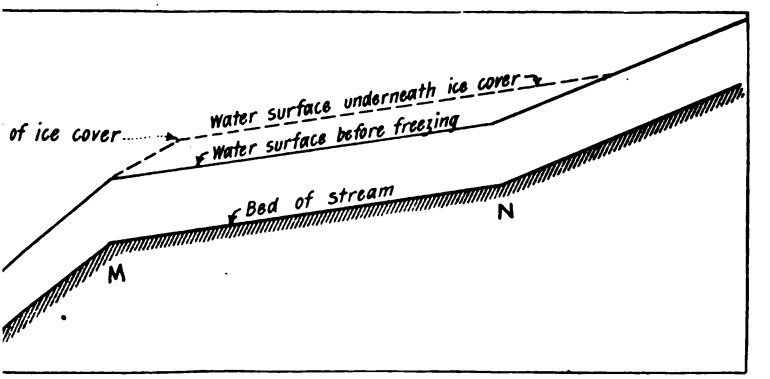


FIG. 2.—Effect of freezing on a smooth section of a river terminated by rapids.

the following conditions: (1) There will be an increase in the iction due to replacing the water-air contact surface by watertact surface; (2) if the discharge remains the same, it follows ith increased friction either the slope or the cross-sectional area ıcrease.

long, uniform channel, frozen throughout, there can be but little ncrease in slope; but in short reaches separated by open water, ; those where gaging stations are commonly located, an appreclocal increase in slope due to freezing may easily occur, as in fig. 2. As a result of freezing of the smooth-water reach

M N there is a tendency for the stage to be raised, as shown by the dotted line, and the upper stretch of quick water above N may be partly submerged by backwater. If the discharge remains the same the depth of open water at M will not be increased unless there is backwater here due to ice cover below this point. If the depth at M is not increased, the fall of the water surface between N and M will have been increased. There is no actual increase in slope, except in the vicinity of M, and the ice surface adjusts itself parallel to the channel bed, as in the case of flow in an open channel, but the effective fall from N to M is of course increased.

CHANGE IN AREA OF WATERWAY REQUIRED BY FREEZING.

The conditions that occur when a broad river becomes covered with a uniform ice surface are illustrated by the following example: Consider a rectangular channel in which the width B D is many times the depth, so that the wetted perimeter may be taken as approximately equal to the width. Neglecting the air friction, call the coefficient of roughness applying to the channel n_1. Consider also that the cover E F may be brought just in contact with the stream surface, the coefficient of roughness for this ice cover being n_2. The slope and discharge being assumed to remain constant, the effect of cover of varying roughness may be illustrated as follows:

Let width B D = 500 feet,
slope S = 0.0005,
depth D = 5 feet,
area of section = 2,500 square feet,
wetted perimeter = 500 feet approximately,
hydraulic radius = 5 feet approximately.

Then for $n = 0.030$, as in an ordinary river, the mean velocity would be 3.29 feet per second, and the discharge would be 8,225 second-feet.

If, now, the stream is covered over, if n_1 and n_2 equal 0.030 each, and if the discharge is the same as before, then the stream stage must evidently rise in such manner that the increase in C, resulting from increased hydraulic radius, together with the increase in R and A, will counterbalance the increased friction. Owing to the complexity of the Kutter formula, the result can best be determined by successive approximations rather than by analysis.

We will have, if D remains as before,

R = 2.5 V = 2.01 Q = 5,025

If D is increased 1 foot,

R = 3.0 V = 2.29 A = 3,000 Q = 6,870

If D is increased 2 feet,

R = 3.5 V = 2.56 A = 3,500 Q = 8,960

By interpolation between the last two values it appears that the

be somewhat more than half of the total cross-sectional bound-
rthermore, as shown elsewhere (pp. 14–15), when the stream is
l, the effect is to replace air-surface friction by ice-surface fric-
› that, all things considered, the presence of a thin, smooth ice
ill probably not necessitate any very great increase in stage in
› maintain the discharge undiminished.
river becomes nearly or quite frozen over and the thickness of
eases, the diminution of area of water may be considerable. In
ample previously quoted, for the given stage the area of
ay would be reduced as follows (if the ice is floating):

Effect of thickness of ice on area of waterway.

Thickness of ice.	Reduction in area of waterway.	
Feet.	*Sq. ft.*	*Per cent.*
0.5	230	9.2
1	460	18.4
1.5	690	27.6
2	920	36.8

ı ice 2 feet thick, then—which is not uncommon—there would
duction in area of about 37 per cent. In the example, above, a
stage of 0.2 foot was occasioned by thin ice cover. With 2 feet
ss of ice a further rise of about 1.84 feet, with no snow load
he ice, would be required to insure the same discharge. The
ecessary rise of stage would then be 2.04 feet.

EFFECT OF THICKNESS OF ICE ON FLOW.

evident that the discharge for a given gage height, taken to the
surface where there is a thick ice cover, may be diminished very
ally as compared with that for open-water conditions.
urther considering the data on page 18, and also assuming a
in depth (or gage height) from 5 to 8 feet, we obtain the
ng:

Relation of gage height to discharge.

[$S = 0.0005$; $n = 0.030$ for open water; $n = 0.020$ for thin ice cover.]

Depth (or gage height).	Discharge (open section).	Ratio: Discharge under ice cover. / Discharge for open section.		
		Thin ice.	Ice 1 foot thick.	Ice 2 feet thick.
Feet.	*Second-feet.*			
5.0	8,225	0.91	0.65	0.42
6.0	11,200	.91	.70	.49
7.0	14,500	.92	.73	.55
8.0	18,200	.92	.74	.59

For the rectangular section as chosen this indicates that for a given stage the ratio of discharge under ice cover to that for open section diminishes as the ice thickness increases; for thin ice cover it is

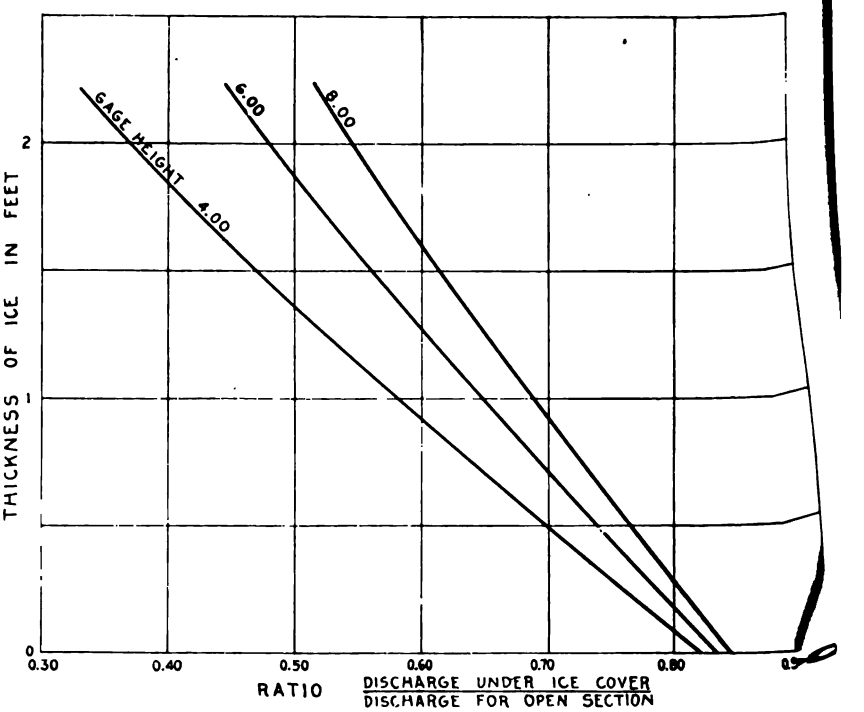


FIG. 3. Effect of change in stage on discharge under ice cover, with varying thickness of ice.

approximately constant for ordinary stages, but as the ice thickens the effect on the ratio is much greater at the lower gage heights. To further illustrate this tendency, fig. 3 has been prepared. The properties of the gaging cross section of the Connecticut River at Orford, N. H., are here used (at gage height 4.0; area = 1,280; width = 267; hydraulic radius = 4.76; slope assumed as 0.00012; $n = 0.035$ for open-water conditions; and $n = 0.025$ for channel frozen). Under these assumptions with thin ice, the relation between discharge under ice

· and that for open water is nearly constant for ordinary stages; ıick ice this relation may vary 25 or 30 per cent in this range of heights (which is about the usual winter range at this station), endency being for this ratio to increase as gage heights increase.
ıe effect of a thickening ice cover for given conditions of slope and ıness and for a given gage height is as follows: (1) To diminish ross-sectional area; (2) to slightly diminish the wetted perimeter, ssening the width; (3) to decrease the hydraulic radius as a result e loss of area while the wetted perimeter changes only slightly.
ıanges of area and hydraulic radius both tend to diminish flow. evident that the relative effect of this diminution will become less less as stage increases, for both area and hydraulic radius increase tly as the gage height, while the loss of area and hydraulic radius given thickness of ice is approximately the same at any ordinary

METHODS OF OBTAINING WINTER RECORDS.

CURRENT-METER STATIONS.

GAGE HEIGHTS.

evious to the winter of 1903–4 records of gage heights for the n season were not in general obtained, the exception being in the of a few gaging stations on Catskill Mountain streams in the ity of New York City, where the attempt was made to procure inuous records from the time of their establishment in 1901. e 1903 gage heights have been procured during the winter at a iderable number of stations in the Eastern and Central States. ffort has been made to obtain data bearing on both the stage of iver and ice conditions.
ıe observer is not expected to read the gage and obtain the attend- ice data oftener than once or twice a week unless unusual condi- s prevail (such as high water, due to rains or melting snow), as the ıge in stage under ice cover is usually a slow and even one. The ıtials in these observations are as follows: (1) A hole is cut in the t (or underneath) the gage, the gage is read to the water surface to the top of the ice, and the thickness of the ice is measured; (2) special conditions are noted, either in remarks or by sketch, such eas of open water, backwater effect due to ice jams, etc. Observ- ıre instructed to measure the thickness of ice occasionally at other es in the cross section at the gage and at points up and down ım. For these winter duties observers are furnished with an ice el and an ice-measurement stick, so arranged with an L end that ottom of the ice can be definitely located and the thickness noted. he transition periods from open channel to frozen conditions in the and the reverse in the spring are important. During the fall- sition period, while the river is freezing, two methods have been

used for gage readings, as follows: (1) Daily gage readings to the to of the ice are made continuously, until the ice is strong enough walk on, the date of first freezing having been noted. After the i cover forms the usual winter observations begin, as previous described. (2) The ice is broken daily under the gage, a good-siz hole being made with a weight and rope provided for the purpose, ar gage heights are read to the water surface, until the ice is stro enough to walk on, when the thickness can be noted and the usu method followed.

In spring when the ice goes out daily gage readings begin with ar considerable increase in stage and conditions as to ice—time of i going out and of river being clear from ice, etc.—are noted. If at ar time during the winter high water occurs or the ice goes out, daily ga readings are resumed until steady conditions once more prevail.

CURRENT-METER DISCHARGE MEASUREMENTS.

Holes are cut in the ice at points in the cross section where it desired to obtain velocity determinations. These holes can be c usually to best advantage with an ice chisel and are made only lar enough to allow the ready lowering of the current meter through the A rectangular hole 12 by 24 inches, with its length in the direction the cross section and with vertical sides, has been found convenie for thick ice; lesser dimensions may be used where the ice is thin. a few cases it has been necessary to cut a continuous channel betwe two or more adjacent holes, especially where the holes are clo together, to prevent rapid vertical pulsations of water in the hol Where a large number of holes are to be cut, a special auger cutti out a cylindrical core of ice has been used to advantage by Unit States Army engineers. The auger is driven by hand, by means a suitable framework and gearing, similar to a carpenter's frame bo ing machine.

The cross section at which open-water discharge measurements a made is always used, when possible, as more direct comparisons c thus be made of the various features of flow under ice cover, wi similar data for open channel. If, as sometimes happens, it is des able that the measurements of flow under ice cover be made at different or auxiliary section in order to obtain more favorable con tions, it is necessary to install an auxiliary gage or reference point, by sufficient soundings at the section used to keep control of the ar positions of ice surfaces, etc.

Soundings are always referred to the surface of the water in t holes, and, in addition, the distance from the water surface to the t and the bottom of the ice is noted. The depth of snow covering t ice, if any, is also noted and if possible a determination made of

water equivalent. The character of the ice and of its under surface is noted, especially with regard to smoothness.

Gage heights are taken to the water surface and the top of the ice in the same way as by the observer, but, in addition, especially if an auxiliary section is being used for the current meter, holes are cut in the gage cross section and a little distance up and down stream in sufficient number to get a good average determination of the thickness of the ice and its position relative to the water surface.

Velocity observations have been most generally made by the vertical velocity-curve method, or at least a sufficient number of curves have been obtained to give good control of any single or double point method. Vertical velocity curves have also been very frequently taken for the reason that data were thus obtained for study and for the devising of shorter methods of observation.

A double-point method giving good results was developed from data obtained in 1904 and was used in measurements for the next two seasons. This consists in making observations at 0.2 and 0.8 of the total depth (below the bottom of the ice), the mean of these two velocities being very nearly the mean velocity of the vertical.

Single-point methods, in which the velocity is determined at 0.4, 0.6, or mid depth, are sometimes used, it being necessary to have vertical velocity curves at the same points and taken under similar conditions in order to deduce the mean velocity from the observed velocity.

Vertical integration has been used to a limited extent, but it has not been found as convenient as the methods previously described and it gives no data for the study of the vertical velocity curve. It is also objectionable owing to the difficulty of properly handling the current-meter cable, which becomes wet and covered with ice.

The horizontal distance between velocity observations should probably be about the same as for open water for the best results, but frequently it is advisable to extend it somewhat beyond that limit, in order to reduce the labor required for cutting holes in the ice.

The current meter is used either suspended by a cable in the ordinary manner or fastened to a wooden or metal rod. If a cable is used, it is marked at intervals of 0.5 or 1 foot by small lengths of cord wound and tied about it for use in sounding and placing the meter. It is most convenient to refer these to the center of the meter and add to soundings the distance from the center of the meter to the bottom of the weight. If a rod is used (this is of course limited to comparatively small depths and low velocities), it may be graduated from the center of the meter in a similar way. The rating of the small Price meter when it is fastened to a rod, but free to tip on its horizontal axis, is almost identical with that when the meter is suspended by a cable in the usual way.

The meter must be kept in the water continuously, or nearly so, if the temperature of the air is much below freezing, as ice will form very quickly on exposure and perhaps cause the meter wheel to stick. If the temperature is very low, trouble is also experienced from ice gathering on the cable or rod supporting the meter.

Measurements during inclement weather can often be most conveniently made under a shelter consisting of a framework of light boards or poles covered with canvas. A cross plank at a height of about 3 feet serves as a convenient support for instruments and stop watches, as well as a datum for lowering the meter in making vertical velocity curves.

In moving from station to station the meter is drawn up until it clears the ice and left suspended from the cross plank while the entire shelter is carried forward to the next point of measurement. By this method the necessity of handling the wet cable, often troublesome, even when rubber mittens are used, is generally avoided.

The additional cost of measurements on frozen streams over that for the open season is occasioned by the following conditions: (1) General difficulty of field work during cold weather, and consequently longer time required; (2) labor required to cut holes in ice and perhaps clear off snow; (3) longer methods required in gaging. The following table gives data regarding the cost of gaging under ice cover at certain stations during 1904–1906 as compared with the cost of gagings made under open-water conditions.

Cost of current-measurements under ice cover.

Locality.	Number of stations	Year.	Number of gagings.	Average cost per gaging, exclusive of travel to and from station.	Average total cost per gaging.	Usual total cost per gaging, river open.
New England	1	1904	4	$30.52	$34.64	$10.00
Do	3	1905	7	16.67	18.82	8.57
Do	4	1906	19	14.18	15.65	10.42
New York	9	1906	15	18.24	22.13	10.32

The "usual total cost per gaging, river open," is based on a record of actual costs during 1904 and 1905 for New England and from July, 1904, to July, 1905, for New York stations. During the greater part of the 1906 winter gagings in New England only one hydrographer was in the field, laborers being employed for the work of cutting holes in the ice and assisting in gaging. Previous to that time there were usually two hydrographers. All New York gagings have been made by two hydrographers.

The average cost per gaging for ice cover, exclusive of travel, is from one and one-half to three times that for open-water conditions.

A GAGING STATION ON SANDY RIVER AT MADISON, ME. AT DAM OF MADISON ELECTRIC COMPANY.

B. GAGING STATION ON WINOOSKI RIVER AT RICHMOND, VT.

STATIONS AT DAMS.

A considerable number of the gaging stations of the Survey are at water-power plants, and records are obtained by observing the flow over the dam, the wheel-gate openings, etc., and the amount of water used by wheels.

During cold weather ice may form in large quantities on the crest of a dam and vitiate the computations made from gage heights of flow over the dam. Pl. I, *A*, gives an excellent illustration of the manner in which ice may form upon a dam. This plate shows one of the regular stations of the Survey at Madison, Me. In some cases this difficulty can be obviated by keeping the ice cut away from the crest, as is frequently done at an electric-light and power plant; or where that is impracticable, a record of ice conditions, with proper corrections, may serve to make approximate estimates.

The flow through turbines is as easily determined in winter as in summer. Frequently the greater part of the flow is taken through the wheels. Gaging stations at dams and mills usually afford better opportunities for securing winter records than exist at many current-meter stations.

ESTIMATES FROM PRECIPITATION.

Methods of estimating stream flow from precipitation are so generally known as to require no detailed explanation. In most such estimates the run-off in any month is determined from the contemporaneous precipitation by the use of a ratio or reduction factor. In crude estimates it is assumed that a constant percentage of the precipitation will appear as run-off regardless of the amount of precipitation. In more exact work a sliding scale of coefficients is used, the values depending on the amount of precipitation and the month or season.

For precipitous and impervious basins the run-off will be nearly coincident with the precipitation. If, however, there are lakes, forests, extensive ground-water storage, or accumulated snow within the basin, the precipitation in one month may not appear as run-off for a considerable interval of time, and any attempt to estimate the run-off for any month from the contemporaneous precipitation will be valueless. This is especially true in basins where much of the winter precipitation is in the form of snow, which accumulates on the ground, especially in ravines and forests, so that water representing several inches depth on the drainage basin may be carried forward from month to month, or from one calendar year to another, without entering the stream.

A heavy precipitation in the form of snow may occur without any appreciable effect on the stream flow. On the other hand, whenever the temperature rises above 32° F., run-off from melting snow occurs,

and often the entire winter's snow storage enters the stream in th course of a few days. During from one to three months of th spring freshet season northern streams generally show a run-off cor siderably in excess of the contemporaneous precipitation.

Data regarding the evaporation loss from snow-covered surface are very meager. If records of the snowfall, snow accumulation, an temperature are at hand it may be possible to form estimates of th total run-off of a stream for the winter season. It is obviously impos sible at present to form reliable estimates of winter flow for shorte periods from precipitation data alone in any manner similar to tha commonly used in estimating the flow from the rainfall during th summer months.

The minimum flow of a stream, either in summer or winter, ord narily occurs at times when there is no direct surface run-off and whe the permanent supply from ground water, lakes, or storage reservoi is at a minimum.

The presence of snow with low temperature effectively cuts c direct surface inflow in winter, sometimes for a period of sever months. Careful studies of the laws of supply to a stream fro ground water during either summer or winter droughts will be of val in estimating the winter regimen.

With present knowledge it is evident that actual measurements flow from gagings are even more needful in winter for the determir tion of available water supply from streams than in summer, althou in the existing data of stream flow the winter period is to a consid able extent neglected.

WINTER RECORDS.

Data on open-water and winter conditions and the dischar measurements made during the frozen season are here given for t following stations:

Catskill Creek at South Cairo, N. Y.
Connecticut River at Orford, N. H.
Esopus Creek at Kingston, N. Y.
Fish River at Wallagrass, Me.
Kennebec River at North Anson, Me.
Rondout Creek at Rosendale, N. Y.
Wallkill River at Newpaltz, N. Y.
Winooski River at Richmond, Vt.

CONDITIONS AT STATIONS.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

This station was established July 4, 1901. It is located at t highway bridge in the village of South Cairo, about 1 mile north of t Catskill Mountain Railroad station for that place. The drainage ar

is 263 square miles. Measurements are made from the downstream side of the bridge at ordinary and high stages, and by wading a short distance above the bridge at low stages.

The drainage basin of this stream receives the run-off from the north slope of the Catskill Range and lies for the most part in the timbered highlands of Greene County. The source of the creek is in a swamp at Franklinton, Schoharie County. It enters Hudson River at Catskill after traversing Greene County for nearly 25 miles. The stream flows over a rocky bed through the greater part of its course, having a total fall of 1,200 feet. At the station the bed consists of gravel and rock, the main channel lying nearest the right-hand abutment of the bridge, which has a clear span of about 194 feet. About two-thirds of the way across is a gravel bar covered with brush which affects the discharge to some extent in high water and at low-water stages rapids about 1,800 feet below the bridge tend to cause slack water at the regular section for gaging. Both banks are high and not subject to overflow. The left bank is wooded; the right is rocky and abrupt. Below the bridge the stream is fairly straight for about 1,000 feet; it then curves to the left and flows over some rifts, which at ordinary stages narrow the stream from about 200 to about 30 feet. Above the bridge the course is straight for about 500 feet; there is then a slight turn and some rapids that narrow the channel down to 80 or 90 feet, the width at the bridge being about 125 feet. A portion of the stream bed is permanent, the gravel bar on the left-hand side having a tendency to shift.

From Hudson River to the mouth of Kaaterskill Creek, about 2 miles, there is practically no velocity. From Kaaterskill Creek to Leeds, 3 miles farther up, Catskill Creek flows through a gorge of bluestone, in which it has a fall of about 180 feet. Two dams formerly utilized a portion of this head at Leeds. There is no interference at the station, however, as it is about 3 miles farther up. The extreme stages observed are as follows:

Extreme stages observed on Catskill Creek at South Cairo, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	11.7	18,600
Low water	2.25	18
Extreme range	9.45	18,582

Catskill Creek in this vicinity usually freezes over about December 1, and the general breakup comes about March 1, the stream being partly free from ice for short periods in January or February during what is commonly known as the January thaw. The entire width is usually frozen from a point 500 feet above the station to a point about

1,500 feet below; the rapids seldom freeze except in the coldest weather. Needle ice is produced in abundance in this stream, the observer reporting that the channel is obstructed by this kind of ice for the greater part of the winter.

Ice conditions on Catskill Creek at South Cairo, N. Y.

SEASON OF 1903–4.

November 29, ice 0.6 foot; practically the same up to December 13.
December 17, ice at gage 0.88 foot.
December 19, ice at gage 1 foot.
December 20, rains; creek broken up.
December 27, ice at gage 0.25 foot.
December 31, ice at gage 0.6 foot.
January 1–22, ice averaged about 0.65 foot.
January 23–26, inclusive, ice broken up.
January 27 to February 8, ice from 0.1 to 0.6 foot thick.
February 9, heavy thaw; ice went out.
February 16 to March 3, ice from 0.2 to 1 foot thick.
March 8, heavy rains; ice went out.

SEASON OF 1904–5.

November 27, ice 0.1 foot thick.
December 1–7, ice 0.2 foot thick, increasing to 1 foot by December 27.
December 28, creek broken up.
January 5, creek filled with anchor ice.
January 7, anchor ice broken up.
January 15, creek filled with anchor ice.
January 25–28, ice 0.5 foot thick; stream frozen across to about same thickness above and below gage. Observer states that stream is filled with anchor ice attached bottom, except in narrow strip along gage. Conditions continued the same for three weeks with exception that general ice thickness increased from 1.2 feet upstream to 1.5 feet downstream from gage.
February 18, stream frozen over except along right bank, where ice becomes honeycombed and is broken.
February 25, stream frozen across both above and below gage 1.08 to 1.25 feet thick. Observer states that ice is gradually melting, and shows channel near left bank below gage.
March 1, ice throughout 0.83 to 1 foot thick, but narrow channel on each side.
March 19, ice broken up.

SEASON OF 1905–6.

December, some ice about the middle of the month, but river not frozen solid.
January 8, ice about 0.17 foot thick.
January 9–11, ice 0.25 foot thick.
January 12–14, ice 0.33 foot thick.
January 15, ice 0.25 foot thick
January 24, ice broken up.
February 1, about 0.83 foot of ice both above and below gage, also at gage.
February 22, ice broken up.
February 28, creek filled with anchor ice, both above and below gage.
March 5, ice went out about this date.

The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Catskill Creek at South Cairo, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901-2	2.90	4.82	1.92	1.37
1902-3	3.08	4.90	1.82	.16
1903-4	3.10	4.55	1.45	.54
1904-5	2.80	3.05	.25	.17
1905-6	2.70	5.15	2.45	.83

CONNECTICUT RIVER AT ORFORD, N. H.

This station was established August 6, 1900. It is located at the wooden highway bridge between Orford, N. H., and Fairlee, Vt. The drainage area at this point is 3,305 square miles. Measurements are made from the downstream side of the highway bridge.

The bed of the stream consists of gravel and is permanent. Both banks are high and do not overflow. At the bridge the channel is about 275 feet wide at ordinary stages and is broken by one pier. It is straight for 1,000 feet above the station and for a considerably longer distance below. The channel is about the same width both up and down stream, but at the bridge this width is cut down approximately 13 feet by the pier.

Several small streams enter the Connecticut near Orford, but the only stream of any considerable size is Waits River, about 5 or 6 miles above this point. The nearest dam is at Wilder, about 18 miles downstream. Backwater effect from this dam reaches probably within a few miles of Orford. Upstream the nearest dam is at East Ryegate, about 20 miles above Orford. There is considerable fall in the river in this 20-mile stretch, although it is somewhat concentrated at a few points. The extreme stages observed are as follows:

Extreme stages observed on Connecticut River at Orford, N. H.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	26.1	33,000
Low water	2.0	640
Extreme range	24.1	32,360

Connecticut River in this vicinity usually freezes over about December 1 and remains frozen until the middle or last of March. Near the bridge ice first forms at the shores and around the pier, the left channel always freezing over first and the right channel somewhat later. This portion of the river—from the dam at Wilder to quick water at or above Wells River—has usually a permanent ice cover during the winter months. Anchor or needle ice has never been found here in sufficient quantities to affect gage heights or interfere with gagings.

During the season of 1905–6 the river was completely frozen over at the Orford bridge only from about December 30 to January 24, when a rise in stage carried out the ice. It did not freeze entirely across again during the winter. An area about 1,000 feet long and 150 feet wide, nearly in the middle of the river and extending downward from the bridge, remained open.

Ordinary winter conditions are good at this station, and the range of gage heights is small. Occasionally a winter freshet such as those of December, 1901, and January, 1906, occurs, but these usually last only a few days. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Connecticut River at Orford, N. H.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1900 1	5.8	9.0	3.2	.....
1901 2	3.8	21.7	17.9	.....
1902 3	6.6	8.8	2.2	.....
1903 4	4.0	8.3	4.3	2.
1904 5	4.0	4.5	0.5	2.
1905 6	5.5	20.5	15.0	1.

ESOPUS CREEK AT KINGSTON, N. Y.

This station was established July 5, 1901. It is located at the Washington Street Bridge, Kingston, N. Y., about 1 mile from the West Shore Railroad station. The measurements are made from the upstream side of a two-span highway bridge. The main span is about 117 feet wide. There is also a short span of about 19 feet on the left-hand end for extreme high water. The drainage area above this station is 324 square miles. The bed of the stream consists of earth and loose rock and is permanent. At ordinary stages the channel is from 90 to 110 feet wide at the bridge, but it is wider above and below. Upstream the channel is straight for about 300 feet. It then deflects slightly to the right. Downstream the channel is fairly straight for 700 or 800 feet. Rapids about 300 feet below affect the low-water

ow. Measurements can be made by wading above the Ulster and elaware Railroad bridge, about 1 mile upstream. The right bank is earth, of medium height and slightly wooded; it is not subject to verflow except at very high stages. The left bank is of ordinary ight, slightly wooded, and subject to overflow in high water. The nditions are such that the overflow can be readily estimated.

Esopus Creek receives numerous small tributaries—mostly small rrential streams — which cause rapid fluctuations in the main treams. The stream channel is usually broad and shallow, the bed eing covered with cobbles and small bowlders, until the vicinity of he gaging station is reached, when the slope is more gradual and the urrent less swift. At Olivebridge, about 20 miles above the station, here is a natural fall of about 22 feet that is increased to 28 feet by a imber dam on the crest of the ledge, and at Glenerie, where the West Shore Railroad crosses the Esopus, about 6 miles downstream, there is a cascade that has a fall of about 56 feet. The final descent to tide-water at Saugerties is made through a fall of 42 feet.

There are no dams in the vicinity of the gaging station, and the channel is unobstructed except by small rapids which affect the low-water flow only. The extreme stages observed are as follows:

Extreme stages observed on Esopus Creek at Kingston, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	25.0	23,400
Low water	3.7	36
Extreme range	21.3	23,364

Esopus Creek in this vicinity usually freezes over about December 1, though the entire stream is not closed up. Ice generally forms first along the shore below the bridge and gradually works upstream, the velocity being swifter on the upstream side. The stream here has a wide range during the frozen season, the gage heights ranging from about 5 feet to 17 or 18 feet. These freshets sometimes occur as often as twice a month, and occasionally clear the creek of ice, this depending somewhat on the time of year and the thickness of the ice. The channel below the bridge sometimes becomes jammed, and in the spring it frequently has to be cleared out with dynamite. There is more or less open channel during the greater part of the winter at this station. Several ice measurements have been made here, and invariably there was a portion of the stream open. There are no reports or indications of needle ice, though it may form at times.

During 1901, 1902, and 1903 there was comparatively little ice in this stream, but in the winter of 1904–5 the ice had a thickness of

about 1.5 feet for a period of about six weeks, ranging from 0.1 to 0. feet at other times. The ice went out about March 18. The rang of winter gage heights and maximum thickness of ice observed are a follows:

Range of winter gage heights and maximum thickness of ice on Esopus Creek at Kingsto N. Y.

Date.	Gage height to water surface.			Maximu thickne of ice
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901–2	5.28	9.95	4.67	0
1902–3	6.10	9.82	3.72	
1903–4	4.91	18.23	13.32	
1904–5	4.74	12.90	8.16	
1905–6	5.35	14.60	9.25	1

FISH RIVER AT WALLAGRASS, ME.

This station was established July 29, 1903. It is located ju below the outlet of Wallagrass Brook. The drainage area at th point is 910 square miles. Measurements of the flow are made fr a cable located about 1,500 feet downstream from the gage, soundings are made on the line of the cable. The bed consists gravel and is permanent. The banks are of medium height, b rarely overflow during high stages. The channel is straight for 5 feet above and 300 feet below the cable and is about 100 feet wi being fairly uniform in cross-section near the station. Wallagr Brook is the only stream of any considerable size entering Fi River in this vicinity. The gaging station is about 8 miles above t entrance of Fish River into the St. John and about 2 miles upstrea from an undeveloped fall of about 20 feet. There are no dams in th vicinity. The extreme stages observed are as follows:

Extreme stages observed on Fish River at Wallagrass, Me.

	Gage height.	Dischar
	Feet.	*Second-f*
High water	13.6	8
Low water	1.7	
Extreme range	11.9	8

Fish River in this vicinity usually becomes frozen over abo December 1 and remains so without interruption until about April Ice forms first at the shores and gradually extends across the strea with the exception that in the vicinity of the gage a small a remains open for a time. Occasionally during the winter the thins out, owing to the entrance of water from springs. Win freshets are unusual in this vicinity. Winter conditions are v uniform, fluctuations in stage are usually slow, and the ice cove

nooth and permanent, so that in general this station is especially ıvorable for records. The range of winter gage heights and maxiıum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Fish River at Wallagrass, Me.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1903-4	2.8	5.0	2.2	.....
1904-5	3.3	5.2	1.9	1.9
1905-6	2.0	5.2	3.2	1.5

KENNEBEC RIVER AT NORTH ANSON, ME.

This station was established October 18, 1901. It is located 1½ miles east of North Anson village and a short distance above the mouth of Carrabassett River. The drainage area at this point is 2,880 square miles. Measurements are ordinarily made from the covered wooden highway bridge, known locally as Patterson Bridge.

The bed of the stream is rocky, with stone and gravel in places, and is permanent. The right bank is high. The left bank is of medium height and is subject to overflow in times of highest water. At the bridge the channel is about 350 feet wide, broken by one pier. It is straight for about 100 feet upstream and 200 feet downstream from the bridge and is curved beyond these points. The channel widens out to about 500 feet a short distance up and down stream from the bridge.

Carrabassett River enters the Kennebec about 1 mile below Patterson Bridge, and at its mouth is a large island dividing the Kennebec into two narrow channels. The nearest dam is at Madison, 6 or 7 miles downstream, and backwater from this dam extends about to the mouth of Carrabassett River. Upstream the nearest dam is at Solon, about 8 miles above; the slope of the river in this portion at ordinary stages is in general about 4 feet to the mile, although it is concentrated somewhat at several points. At low water the velocity at the bridge becomes somewhat low and poorly distributed, and measurements have been made by means of a boat at a distance of about 1,000 feet downstream. The extreme stages observed are as follows:

Extreme stages observed on Kennebec River at North Anson, Me.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	14.95	39,000
Low water	1.55	800
Extreme range	13.40	38,200

Kennebec River in this vicinity usually becomes frozen over during the first week in December and remains so without interruption until about March 15 or April 15. Near the bridge ice first forms at the shores and around the piers and gradually extends, the channel being completely frozen over in a week or so in ordinary seasons. During the winter of 1905–6, however, narrow channels remained open in each span until about January 1, and narrow areas of open water remained somewhat after this date for short distances above and below the bridge.

In December there is probably considerable needle and anchor ice in the vicinity of the station, but after the ice becomes permanent no trouble has been occasioned from this source.

Ordinary winter conditions are good for recording gage heights at this station. The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Kennebec River at North Anson, Me.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1903–4	2.3	4.8	2.5	1.8
1904–5	3.8	6.6	2.8	2.7
1905–6	3.4	5.8	2.4	2.0

RONDOUT CREEK AT ROSENDALE, N. Y.

This station was established July 6, 1901. It is located at the highway bridge in Rosendale about one-half mile downstream from the Wallkill Valley Railroad station. The drainage area above this point is 380 square miles. There is some diversion through the Delaware and Hudson Company's canal, which is parallel to the river and is operated during the summer months from High Falls to tide water in Hudson River at the mouth of Rondout Creek. This canal receives its supply from Rondout Creek at High Falls, 3 miles upstream from Rosendale, but a large percentage of this diversion returns before reaching the gaging station. Observations made at Creeklocks of the stage of water in the canal and a record of the number of lockages afford sufficient data to estimate the flow through the canal. As the canal is closed during the winter months, it has no effect on the winter's record.

At the gaging station the bed of the stream consists of rock and is permanent. The channel at the bridge ranges from 90 to 135 feet in width and widens out considerably both above and below the bridge. It is straight for several hundred feet each way from the bridge, and some rifts about 1,000 feet downstream cause slack water at low

when measurements are made at a ford about 1 mile below. anks are high and rocky and are not subject to overflow. asses under the bridge at all stages.

is practically 75 feet fall from the diversion dam near High out 3 miles above the station, to the junction with Wallkill about 3 miles below. There are no streams of importance into Rondout Creek in the neighborhood of Rosendale. The stages observed are as follows:

Extreme stages observed on Rondout Creek at Rosendale, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
	19.40	18,130
	6.00	50
ne range	13.40	18,080

out Creek usually freezes over about December 1 and the ice about March 1. There are usually two or three freshets durperiod that break the ice up and in most cases carry it out. ecord was discontinued November 7, 1903, but started again ecember 1, 1905, by the city of New York. The 1905–6 rec- w that the river was not closed by ice until about February 3 t the ice went out February 22. The range of winter gage and maximum thickness of ice observed are as follows:

inter gage heights and maximum thickness of ice on Rondout Creek at Rosendale, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
	6.95	9.35	2.40	0.42
	6.95	9.85	3.10	.40
	5.04	5.60	.56	.46

WALLKILL RIVER AT NEWPALTZ, N. Y.

tation was established July 7, 1901, and was discontinued er 19, 1903. It was located at the highway bridge in New- ar the Wallkill Valley Railroad. The drainage area above it is 736 square miles. The measurements were made from istream side of the highway bridge at all times except during high water, when the Wallkill Valley Railroad bridge about below was used. At low stages the water is rather slack and cult to obtain a satisfactory measurement. The bed of the composed of clay with large cobblestones and some bowlders,

and is permanent. Upstream the channel is straight for 400 or 500 feet; it then bends rather sharply to the right; downstream it is straight for several hundred feet. The right bank is rather high and slightly wooded, and does not overflow. The left bank is of medium height and is subject to overflow during high-water stages.

The principal tributary to the Wallkill in the vicinity of Newpaltz is the Shawangunk Kill, which enters near Gardiner, about 7 miles above, its total drainage area being 149 square miles. The dam nearest the station is at Walden, about 12 miles above. At low stages slight rapids about 300 feet below the bridge cause slack water in places and affect the discharge; at extreme high water a plain on the left side is overflowed, making it impossible to determine the flow at this point. The extreme stages observed were as follows:

Extreme stages observed on Wallkill River at Newpaltz, N. Y.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	24.8	24,480
Low water	5.5	105
Extreme range	19.3	24,375

While Wallkill River freezes more or less in December, there are no records that show the stream to be completely closed before January, and then only for short periods. Several discharge measurements under ice cover have been made, some showing backwater from ice and others giving fairly good results. In general, however, the river is partially open during the entire winter season, except in parts of January and February. The ice usually goes out about March 5.

Ice records on Wallkill River at Newpaltz, N. Y.

1902.

January 12, ice 1.2 feet thick.
January 19, ice 1.2 feet thick.
January 26, ice 1.2 feet thick.
February 2, ice 1.3 feet thick.
March 1, high water.

1903.

December 11, 1902, to January 4, ice about 0.5 foot thick.
January 4–17, ice 0.83 foot thick.
January 18–24, ice 0.92 foot thick.
January 25–31, ice 0.83 foot thick.
February 1–26, ice 1 foot thick.
February 28, ice went out under bridge.
March 1–4, ice 200 feet above and 300 feet below bridge.
March 5, river clear.

The range of winter gage heights and maximum thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Wallkill River at Newpaltz, N. Y.

Date.	Gage height to water surface.			Maximum thickness of ice.
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1901-2	7.20	18.50	11.30	1.25
1902-3	7.05	16.55	9.50	.82

WINOOSKI RIVER AT RICHMOND, VT.

This station was established June 25, 1903. It is located at the steel highway bridge about one-fourth mile from Richmond railway station on the road to Huntington. The drainage area at this point is 885 square miles. The bed consists of sand and gravel and is fairly permanent. The banks are fairly high, but overflow at extreme high water. The channel is slightly curved upstream, but straight for 1,000 feet or more downstream. It is about 175 feet wide at the bridge, and somewhat wider above and below. The nearest dam downstream is at Essex Junction, about 8 or 9 miles below the station, and there is a considerable amount of undeveloped fall between these two points. Upstream the nearest dam is at Bolton Falls, about 7 or 8 miles above the station. The extreme stages observed are as follows:

Extreme stages observed on Winooski River at Richmond, Vt.

	Gage height.	Discharge.
	Feet.	*Second-feet.*
High water	18.7	+19,000
Low water	3.7	139
Extreme range	15.0	±18,861

Winooski River in this vicinity usually freezes during the first part of December and remains frozen until about March 15. That part adjacent to and below the bridge, where the velocity is medium, freezes first. About one-fourth mile upstream, where a stretch of quick water begins, freezing takes place considerably later, and during some winters a permanent ice cover does not form here.

The contraction in the channel at the bridge tends to cause ice jams, and low velocity just below favors the formation of thick ice. During the January freshet of 1906 a jam affected gage readings during the remainder of the winter season. Pl. I, *B* (p. 24), shows the conditions at the gaging section March 9, 1906. The ice is extremely

rough, broken, and tilted, and the gage heights give no index w ever of the flow, which was confined to about one-third the ordi width of channel. The range of winter gage heights and maxin thickness of ice observed are as follows:

Range of winter gage heights and maximum thickness of ice on Winooski River at Richmond, Vt.

Date.	Gage height to water surface.			Maxi thick of i
	Minimum.	Maximum.	Range.	
	Feet.	*Feet.*	*Feet.*	*Fe*
1903–4	4.15	6.7	3.55	
1904–5	4.95	5.7	.75	
1905–6	4.9	14.7	9.8	±

Ordinary winter conditions are rather poor for estimates of flow this station owing to the liability of unstable conditions. Dur low stages, which frequently occur in winter, the change in discha is considerable for a slight difference in stage, and a slight change the controlling ice conditions downstream may markedly affect discharge:

GAGE HEIGHTS AND DISCHARGE MEASUREMENTS.

The following measurements have been made at the statio described above.

Stream measurements during frozen season.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height—		Thickness of ice.	Snow on ice.	Gage height to water surface.		Gage hei to bott of ice.	
					To water surface.	To bottom of ice.			Discharge for open-water conditions.	Coefficient for reducing open water to ice conditions.	Discharge for open-water conditions.	Coefficient for re-
1901	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
December 9	[a] 65	106	1.03	110	3.30	2.93	0.37	.....	120	0.92	66	
1902												
January 15	90	166	.89	148	3.50	2.84	.66	.....	152	.97	53	
1906												
February 16	100	190	.33	62	2.82	2.22	.70	.....	56	1.11	17	

[a] Gaging made 70 yards below bridge.

Stream measurements during frozen season—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.

ste.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
903.	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Second-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Second-feet.*		*Second-feet.*	
y 24	276	1,760	1.69	2,970	7.33	6.00	.....	.....	4,925	0.60	3,470	0.86
y 29	273	1,610	1.63	2,620	6.71	5.40	.....	.....	4,240	.62	2,880	.91
y 29	273	1,620	1.66	2,690	6.75	5.50	.....	.....	4,285	.63	2,975	.90
y 30	276	1,760	1.69	2,980	7.30	6.00	.....	.....	4,800	.61	3,470	.86
ıry 7	278	1,810	1.65	2,990	7.38	6.05	.....	.....	4,980	.60	3,520	.85
ıry 7	278	1,810	1.67	3,030	7.40	6.05	.....	.....	5,000	.61	3,520	.86
904.												
ıry 3	240	851	1.00	850	4.20	2.40	2.03	.....	1,880	.45	815	1.04
ıry 3	241	847	.99	840	4.17	2.37	2.03	.....	1,860	.45	801	1.05
ıry 4	239	804	.93	750	4.03	2.23	2.03	.....	1,760	.43	738	1.02
ıry 4	236	804	.95	760	3.99	2.19	2.03	.....	1,735	.44	720	1.05
ıry 5	235	813	93	760	4.03	2.23	2.03	.....	1,760	.43	738	1.03
ıry 5	235	805	95	765	4.03	2.23	2.03	.....	1,760	.43	738	1.04
905.												
ıry 28	235	775	.88	686	4.07	2.30	2.01	0.1	1,790	.38	770	.89
1	235	794	.96	766	4.26	2.40	2.09	.1	1,925	.40	815	.94
1	235	794	.93	739	4.25	2.39	2.03	.1	1,918	.39	810	.91
906.												
ıry 8	327	1,920	1.17	2,250	.84	5.51	1.48	.2	4,380	.51	2,980	.76
ıry 15	327	1,870	1.20	2,240	6.80	5.32	1.48	.9	4,340	.52	2,810	.80
ıry 17	327	1,790	1.14	2,040	6.56	5.06	1.52	.9	4,080	.50	2,570	.79
14	327	1,560	1.08	1,680	6.00	4.56	1.55	.1	3,470	.48	2,160	.78
15	327	1,440	1.04	1,490	5.59	4.15	1.55	.1	3,060	.49	1,840	.81

ESOPUS CREEK AT KINGSTON, N. Y.

901.												
ber 4	86	280	0.84	236	5.28	5.20	0.083	.....	329	0.72	309	0.76
902.												
y 9 *a*	100	419	1.25	522	6.54	6.41	.13	.....	716	.73	669	.78
ry 28 *b*	116	706	2.39	1,690	9.14	8.94	.20	.....	2,030	.83	1,900	.89
ber 11	90	404	1.18	476	1.60	6.50	.10	.....	741	.64	700	.68
ber 1 *c*	116.6	1,170	2.96	3,460	13	.....	.....	.....	5,300	.65	.....	.....
903.												
y 14 *d*	101.6	413	1.03	425	6.9	6.32	.58	.....	864	.49	638	.67
ry 24 *e*	104.6	443	1.47	654	7.1	6.70	.40	.....	950	.69	782	.84
906.												
ry 15	90	287	.87	250	5.60	5.17	.33	.....	412	.61	302	.83

FISH RIVER AT WALLAGRASS ME.

906.												
ry 15	95	205	0.95	195	3.91	2.66	1.25	0.65	620	0.32	225	0.87
.....	95	205	.96	196	3.91	2.66	1.25	.65	620	.32	225	.87
15	115	312	1.21	378	4.99	3.83	1.20	.9	1,080	.35	580	.65
.....	115	319	1.22	390	5.08	3.92	1.20	.9	1,125	.35	620	.63

tly frozen over; stations 20–70 and 110–115 open.
tly frozen over; stations 0–25 and 110–116 open.
r frozen over 150 feet below bridge and 200 feet above. Measurements taken at 0.6 depth. No
idge.
ions 15–40 river open.
ions 12–40 river open; ice rough.

.—February 8 and 17, river partly open for a short distance below bridge. March 14 and 15,
rtly open for a short distance below bridge, but not as much as on February 17.

Stream measurements during frozen season—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
1904.	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Sec-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sec.-feet.*		*Sec.-feet.*	
January 27	240	393	1.90	749	3.40	1.55	1.8	2.0	3,170	0.24	±675	±1.11
January 28	240	398	1.97	786	3.40	1.55	1.8	2.0	3,170	.25	±675	±1.16
March 2	230	285	1.86	529	3.55	1.45	2.1		3,450	.15	±600	±.88
March 4	230	285	2.01	572	3.65	1.55	2.		3,650	.16	±675	±.85
1905.												
February 9	458	1,390	1.50	2,080	5.27	3.27	2.10	1.0	7,530	.28	2,920	.71
Do	458	1,390	1.54	2,140	5.32	3.32	2.10	1.0	7,680	.28	3,020	.71
1906.												
January 9[a]	440	1,100	1.17	1,290	3.58	2.38	1.28		3,520	.37	1,550	.83
January 10[a]	440	1,030	1.09	1,120	3.40	2.22	1.30		3,170	.35	1,370	.82
March 2	445	1,140	1.40	1,500	4.26	2.43	1.97		4,980	.32	1,630	.98
March 3	445	1,050	1.31	1,380	4.08	2.27	1.98		4,580	.30	1,420	.97
March 30	447	1,180	1.36	1,600	4.77	2.67	2.26	.0	6,220	.26	1,950	.82
Do	447	1,200	1.38	1,660	4.80	2.70	2.26	.0	6,300	.26	1,990	.83
Apr 1 11[b]	450	1,210	1.37	1,660	4.70	2.80	1.95	±1.0	6,050	.28	2,140	.79
Do.[b]	450	1,240	1.38	1,710	4.70	2.80	1.95	±1.0	6,050	.28	2,140	.80

RONDOUT CREEK AT ROSENDALE, N. Y.

1901.												
December 6[c]	104	479	0.46	222	6.80	[d]6.54	0.26		415	0.53	253	0.88
1902.												
January 14	105	479	.88	423	7.00	6.53	.47		540	.78	247	1.71
February 8	102	732	1.62	732	8.81	8.41	.40		2,330	.31	1,900	.40
February 26	80	489	1.11	543	8.13	6.71	1.42		1,610	.34	350	1.51
Do	100	517	1.32	684	8.43	7.01	[d]1.42		1,930	.35	549	1.24
1903.												
February 25	115	474	1.6	676	7.9	7.40	.50		4,370	.15	885	.76
1906.												
February 27	117	555	.35	194	[e]5.15	4.51	.46					

WALLKILL RIVER AT NEWPALTZ, N. Y.

1901.												
December 11[f]	135	1,310	2.32	3,040	11.50	10.8	0.70		3,830	0.79	3,250	0.94
1902.												
January 21	80	423	.78	332	7.24	6.04	1.20		860	.39	277	1.20
January 23[g]	140	1,880	3.22	6,060	17.33	16.41	.92		9,290	.65	8,300	.73
January 31[h]	100	679	1.72	1,170	9.07	8.07	1.00		1,980	.59	1,330	.88
February 10	115	496	1.20	597	7.78	6.78	1.00		1,160	.51	619	.97
February 24	85	388	.74	288	7.35	[i]5.25	2.10		919	.31		
1903.												
February 7	140	1,070	2.14	2,290	11.2	10.45	.75		3,580	.64	2,970	.77
February 10[j]	142	999	2.03	2,030	10.9	9.73	1.17		3,330	.61	2,440	.83
February 26	130	757	1.24	945	8.85	7.80	.96		1,830	.52	1,230	.77

[a] Frozen except for narrow channels above and below bridge.
[b] Frozen except for narrow channel near left bank.
[c] Ice varied from one-half inch to 5 inches from bank to bank at riff just below; ice extended one-third way across.
[d] Estimated from previous measurements, same date.
[e] Subject to correction.
[f] Ice cover from stations 40–85.
[g] Ice badly broken at station 20.
[h] Ice badly broken at station 110.
[i] Below rating table; water considerably above top of ice.
[j] Stations 135–142 open.

Stream measurements during frozen season—Continued.

WINOOSKI RIVER AT RICHMOND, VT.

Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Snow on ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open-water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open-water to ice conditions.
1905.	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Second-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Second-feet.*		*Second-feet.*	
March 3	75	109	1.89	206	5.45	2.70	2.95	0	1,460	0.14	.....	.....
March 4	75	114	2.30	262	5.58	2.83	2.95	0	1,610	.16	.....	.....
1906.												
March 9[a]	70	348	1.68	585	5.62	±3.4	±2.8	0	1,650	.35	.....	.....

[a] Channel open 1,000 feet upstream and one-half mile downstream. Ice very rough, broken, and tilted, reaching to bottom for about two-thirds of section.

The following table includes some single sets of discharge measurements, with a brief description of the conditions. As a rule, these are insufficient in range at a given station to give much information regarding the winter rating curve.

Single discharge measurements on frozen streams, 1906.

River and station.	Date.	Width.	Area under ice.	Mean velocity.	Discharge.	Gage height— To water surface.	Gage height— To bottom of ice.	Thickness of ice.	Gage height to water surface. Discharge for open-water conditions.	Gage height to water surface. Coefficient for reducing open water to ice conditions.	Gage height to bottom of ice. Discharge for open-water conditions.	Gage height to bottom of ice. Coefficient for reducing open water to ice conditions.
	1906.	*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*	*Feet.*	*Feet.*	*Feet.*	*Second-feet.*		*Second-feet.*	
Chemung, Chemung, N. Y.[a]	February 17	225	1,040	0.65	674	2.85	2.42	0.53	808	.83	510	1.32
Chippewa, Eau Claire, Wis.[b]	January 25	332	2,772	1.00	2,761	4.82	4.10	.80	3,555	.78	2,010	1.37
Des Moines, Keosaqua Iowa[c]	January 13	565	1,984	1.13	2,260	2.45	2.06	.54	4,415	.51	3,450	.66
Flambeau, Ladysmith, Wis.[d]	January 26	344	501	1.23	632	16.13	15.18	1.20	1,650	.38	730	.87
Genesee, Jones Bridge, Mount Morris, N. Y.[e]	February 12	118	298	1.52	452	5.75	5.36	.49	830	.54	654	.69
Do.[e]	February 13	118	290	1.65	479	5.78	5.47	.41	841	.57	709	.68
Do[f]	February 16	127	373	1.40	525	6.00	5.42	.68	942	.56	687	.76
Genesee, Rochester, N. Y.[g]	February 14	306	1,710	.43	728	1.40	1.00	.50	916	.79	300	2.43
Do.[h]	February 15	360	1,020	.88	894	1.53	1.17	.46	1,110	.80	570	1.57
Hoosic, Buskirk, N. Y.[i]	February 10	130	576	1.23	709	3.90	3.26	.54	1,920	.37	1,260	.56
Maumee, Sherwood, Ohio[j]	February 11	236	507	.77	458	3.34	2.81	.58	886	.52	566	.81
Otter Creek, Middlebury, Vt.[k]	March 10	106	352	3.30	1,160	13.40	12.77	.70	1,360	.85	850	1.37
Raquette, Massena Springs, N. Y.[l]	March 28	174	1,710	3.14	5,370	10.31	8.64	1.92				
Do.[l]	March 29	172.6	1,540	3.07	4,710	8.77	7.45	1.62				
Do.[m]	March 30	172.5	1,740	3.57	6,220	9.73	8.65	1.28				
West Canada Creek, Twin Rock Bridge, N. Y.[n]	February 9-10	175	527	.78	412	3.02	1.84	1.35	1,830	.22	860	.48

[a] Gravel bed; under ice surface smooth; considerable needle ice.
[b] Gravel bed; open 70 feet wide upstream for a long distance; same for about 1,000 feet downstream; then frozen for about 600 feet; then open for a long distance.
[c] Gravel bed; ice rough.
[d] Coarse gravel.
[e] Gravel and sand bed.
[f] Measurements made about 250 feet downstream from regular station.
[g] Gravel bed.
[h] Elmwood Avenue Bridge (regular station); ice smooth on bottom; some needle ice running at stations 100-140.
[i] Considerable needle ice; gravel bed.
[j] Gravel bed; ice rough.
[k] Sand and gravel bed; river open 500 feet below gage for about 800 feet to dam and arch bridge where gaging was made.
[l] Gravel bed; river open, stations 150-175.
[m] River open, stations 0-35 and 130-175.
[n] Gravel bed; under ice surface nearly smooth; a little needle ice.

STATION RATING CURVES FOR ICE COVER.

GENERAL CONSIDERATIONS.

At several stations sufficient data have been gathered to construct a rating curve for conditions of ice cover, applicable to average ice conditions within the range of winter gage heights, but the variation in form of curve with change in thickness of ice is still uncertain, and the proper rating curve or coefficient to apply for the time when the ice is thin has not been sufficiently verified by gagings. A station rating curve for conditions of ice cover must evidently be constructed on one of the following bases: (1) Gage heights to the surface of the water as determined from a hole cut in the ice, or (2) gage heights to the bottom of the ice.

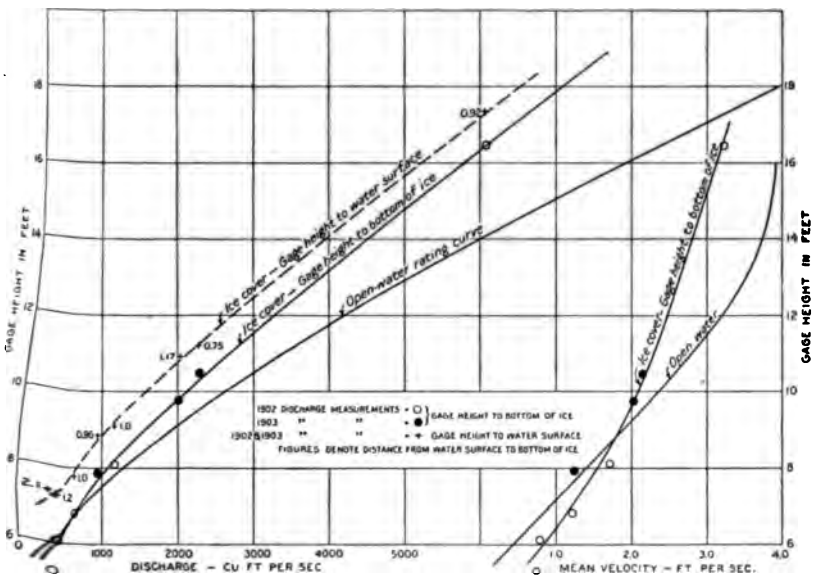

GAGE HEIGHT IN FEET
DISCHARGE — CU FT PER SEC
MEAN VELOCITY — FT PER SEC.
Ice cover—Gage height to water surface
Ice cover—Gage height to bottom of ice
Open-water rating curve
1902 DISCHARGE MEASUREMENTS
1903 " "
1902&1903 " "
GAGE HEIGHT TO BOTTOM OF ICE
GAGE HEIGHT TO WATER SURFACE
FIGURES DENOTE DISTANCE FROM WATER SURFACE TO BOTTOM OF ICE
Ice cover, Gage height to bottom of ice
Open water

FIG. 4.—Rating and velocity curves under ice cover, Wallkill River at Newpaltz, N. Y.

In figs. 4 to 6 are shown the results of such gagings as have been made under ice cover at three gaging stations, the gage heights being plotted in each of the above ways and the open-water rating curve being shown for comparison.

WALLKILL RIVER AT NEWPALTZ, N. Y.

So far as can be determined at present, the rating curve based on gage heights to the water surface seems to give the best results; that is, the points lie more nearly on a smooth curve (fig. 4). There is no great difference, however, except in the case of the lowest gaging, in which the thickness of the ice was perhaps only half of the

distance, 2.1 feet, from the water surface to the bottom of the ice, indicating that the water below the ice was under some pressure. It will be noticed that the range in ice thickness is not large.

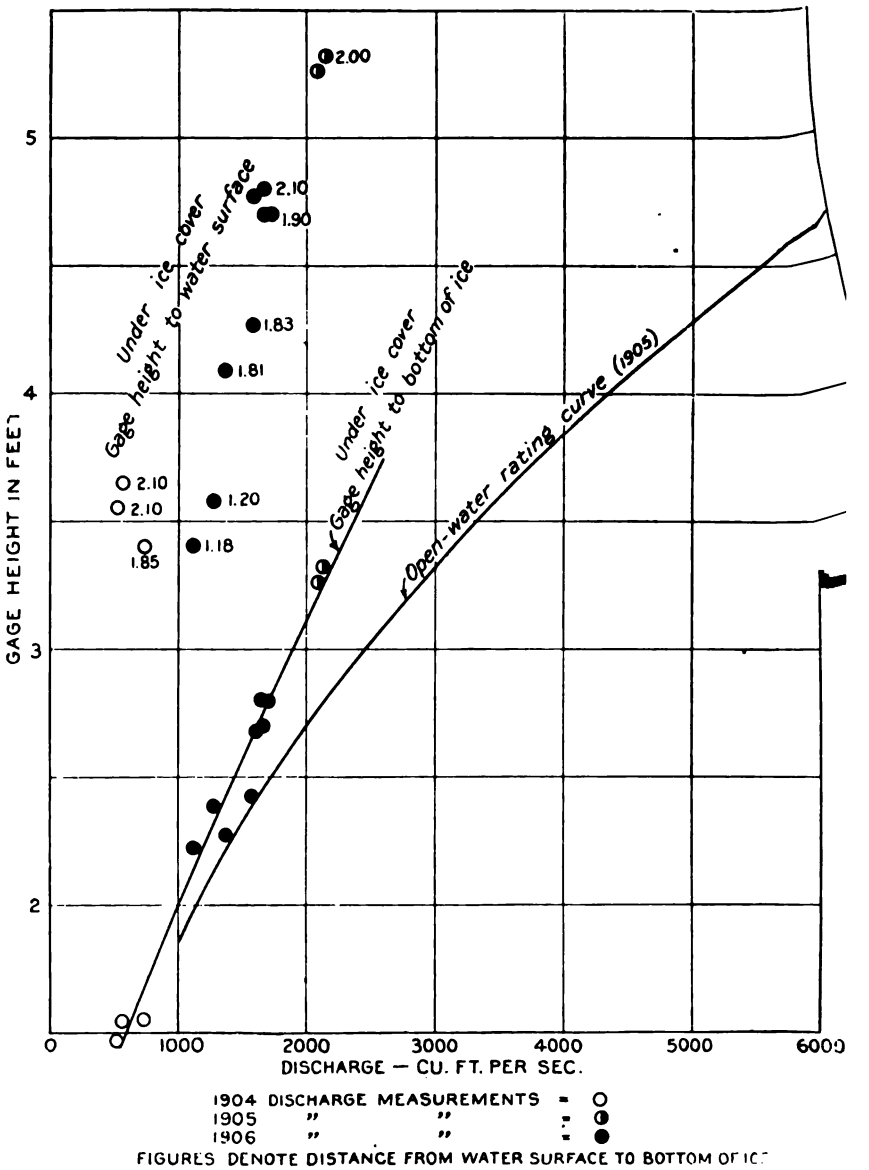


FIG. 5.—Rating curve under ice cover, Kennebec River at North Anson Me.

KENNEBEC RIVER AT NORTH ANSON, ME.

The effect of varying thickness of ice on discharge for a given gage height is clearly shown (fig. 5). No one curve can be drawn through the points plotted for the gage heights to the water surface, although a few

ings would, perhaps, enable a series of curves to be drawn ent distances from the water surface to the bottom of the s preferable to use these distances rather than thickness of or the position of the bottom of the ice with reference to r surface is not only dependent on the ice thickness (in eing about 92 per cent of it), but will also vary with the

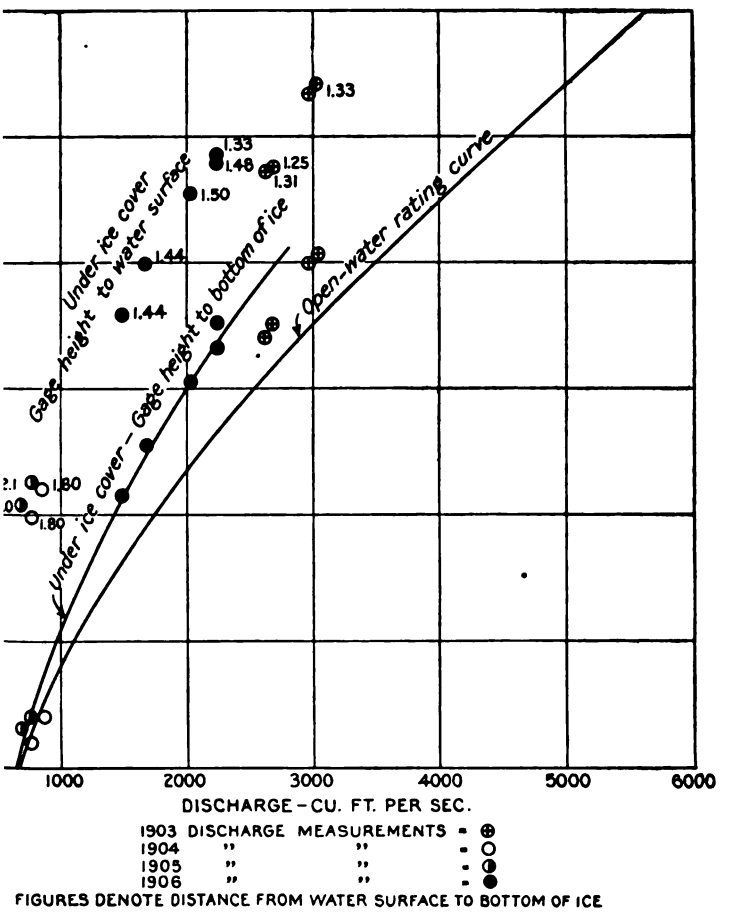


FIG. 6.—Rating curve under ice cover, Connecticut River at Orford, N. H.

l and thus include its effect. If gage heights to the bote ice are used a fairly consistent curve is obtained for this

CONNECTICUT RIVER AT ORFORD, N. H.

ne general results appear here as in the case of the Kenough the range of ice thickness is less (fig. 6). The gagings of 1904 are open to some question, owing to the manner in

Vertical velocity measurements—Continued.

CHIPPEWA RIVER AT EAU CLAIRE, WIS.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 25	4.82	3.92	130	14 3	13.2	1.10	0.52	0.72	0.53	0.47	0.50	0 18	0.13	0.73	2.6	0.19	10.4	0.77	6.2	0.47	0.71	0.72	1.04
			150	13.5	12.4	1 10	.76	.90	.67	.83	.75	39	.58	.92	3.6	.28	11.3	.91	7.8	.63	.83	.84	1.01
			170	12.6	11.5	1.10	1.14	1 38	1.10	1 18	1.14	.40	.54	1.39	2.7	.22	10.0	.83	6.5	.57	.82	.83	1.00
Mean of 3 curves				13.5	12.4	1.10	81									23		.84		.56	.79	80	1.02

CONNECTICUT RIVER AT ORFORD, N. H.[b]

1903.																							
January 20	6.71	5.40	150	.....	6.6	.....	1.92	2 17	2.23	1.65	1.94	22	1.08	2.27	0.5	0.08	4.5	0.68	2.0	0.30	0.84	0.88	0.99
	6.75	5.50	280	.....	9 8	.....	1.94	2.12	2.15	1.82	1.98	13	1 32	2.21	0	.10	7.0	.71	3.0	.31	.88	92	.98
January 30	7.30	6.00	340	.....	6.2	.....	1.85	1.96	1.92	1.86	1.89	22	1.58	1.97	8	.13	5.0	.81	2.5	.40	.94	94	.98
February 7	7.38	6.05	90	.....	7 7	.....	1.58	1.91	1.56	1 62	1.59	76	.85	1.91	7	.22	6.2	.81	3.8	.49	.83	83	1.00
January 30	7.30	6.00	100	.....	6.3	.....	1.73	1 93	1.92	1.53	1.72	15	1.19	2.00	6	.10	4.2	.66	2.3	.37	.86	90	1.00
February 7	7.38	6.05	110	.....	7.2	.....	1.76	1.99	1.94	1.60	1.77	22	1.05	2.04	6	.08	5.1	.71	2.7	.37	.86	88	1.00
Mean of 6 curves					7.3	.....	1.80									.12		.73		.37	.87	89	.99
1904.																							
February 1	4.15	2.45	130	3.8	2.0	2.00	.67	.72	.86	.52	69	50	.33	.87		.05	1.2	.60	.3	.15	.77	93	.97
			140	3.9	2.1	2.00	.40	.42	.60	22	41	48	.00	.61		.....	1.2	.57	.3	.14	.66	95	.97
			150	5.3	3.5	2.00	1.23	1.33	1.48	1.00	1.24	09	.70	1.48		.03	2.4	.68	.7	.20	.83	92	1.00
February 2	3.95	2.25	250	7.7	6.0	2.00	1.04	1.10	1.21	.92	1.06	80	.61	1.21	3	.05	3.5	.58	1.3	.22	.86	95	.98
			260	8.2	6.5	85	.03	1.13	1.16	.92	1.04	74	.52	1.18	3	.05	4.2	.65	2.0	.31	.87	91	.99
			270	8.1	6.4	95	1.11	1.17	1.20	1.03	1.12	93	.82	1.22	5	.08	4.3	.67	1.9	.30	.91	95	1.00
			280	7.4	5.8	1.85	.10	1.20	1.22	.98	1.10	85	.70	1.23	3	.06	3.9	.67	1.8	.31	.89	.92	
February 3	4.17	2.37	200	5.0	3.0	2.25	.61	.66	.78	.43	.60	.55	.20	.78	2	.06	1.8	.60	.4	.13	.70		
February 4	4.03	2.22	110	4.8	3.3	1.70	12	1.20	1.32	.92	1.12	1.13	.68	1.32	.....	.....	2.0						

[a] Gravel bed.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1904.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 5	4.03	2.23	90	5.2	3.6	1.75	0.93	1.03	1.05	0.82	0.94	0.92	0.34	1.06	0.5	0.14	2.2	0.61	1.3	0.36	0.88	0.90	1.00
			100	4.2	2.4	1.95	.96	1.06	1.15	.78	.96	.90	.45	1.15	.4	.17	1.5	.63	6	25	.83	.90	1.00
			340	5.3	4.2	.60	.85	1.02	.98	.77	.88	.83	.00	1.02	.5	.12	2.9	.69	1.7	40	.83	.83	.97
Mean of 12 curves				5.7	4.1	1.91	.92									.07		63		25	.83	.92	.99
1905.																							
February 28	4.07	2.25	100	4.2	3.1	1.3	1.00	1.13	1.00	.98	.99	.58	.80	1.15	.6	.19	2.3	75	1.2	39	.87	.88	1.00
			110	5.0	3.5	1.8	.88	1.02	1.02	.74	.88	.40	.40	1.07	.4	.11	2.3	66	1.2	34	.82	.86	1.00
			120	5.5	3.9	1.8	1.24	1.32	1.36	1.14	1.25	1.00	.93	1.38	.2	.05	2.5	64	1.	28	.90	.94	.99
			150	5.2	3.5	1.9	1.12	1.27	1.34	.89	1.12	1.05	.57	1.37	.2	.06	2.2	63	1.2	34	.82	.88	1.00
			170	5.5	3.7	2.0	1.15	1.23	1.32	.99	1.16	.85	.75	1.33	.2	.05	2.3	62	9	24	.86	.94	1.00
			190	5.0	3.2	2.1	.93	1.04	1.10	.77	.94	.73	.40	1.11	.1	.03	2.1	66	.8	25	.84	.89	.99
			240	5.8	3.6	2.5	.69	.87	.71	.63	.67	.33	.38	.88	.7	.19	2.7	75	1.6	45	.78	.79	1.03
			260	6.7	4.7	2.3	1.13	1.28	1.10	1.16	1.13	.87	.60	1.29	1.0	.21	3.7	79	2.7	57	.88	.88	1.00
			280	6.7	5.1	1.9	1.19	1.33	1.25	1.13	1.19	.83	.85	1.35	.8	.16	3.7	73	2.0	39	.88	.90	1.00
			330	5.5	3.9	2.0	.92	1.13	.97	.82	.90	.30	.60	1.22	.7	.18	2.8	72	1.4	36	75	81	1.02
Mean of 10 curves				5.5	3.8	1.96	1.02									.12		70		36	84	88	1.00
March 1	4.26	2.40	110	5.2	3.6	1.8	1.08	1.25	1.23	.88	1.06	92	.48	1.32	.3	.08	2.3	64	1.3	36	.82	86	1.02
			160	5.7	4.0	1.9	1.28	1.48	1.39	1.15	1.27	1.00	.72	1.53	.6	.15	2.8	70	1.6	40	.84	86	1.01
			180	5.7	3.9	2.	1.14	1.36	1.33	.97	1.15	.62	.23	1.41	.3	.08	2.7	69	1.4	36	.81	84	.99
			200	4.5	2.2	2.6	.76	.83	.80	.72	.76	.56	.56	.83	.2	.09	1.6	73	9	41	92	92	1.00
			250	7.3	5.3	2.3	.94	.96	1.07	.85	.96	.88	.72	1.07	.2	.04	2.9	55	1.0	19	88	98	.98
			270	7.1	5.2	2.2	1.25	1.37	1.32	1.18	1.25	1.00	.92	1.38	.6	.12	3.7	71	2.1	40	91	91	1.00
			320	5.5	3.8	1.8	1.14	1.32	1.27	1.01	1.14	.93	.55	1.33	.4	.10	2.7	71	1.7	45	86	86	1.00
			340	5.6	4.8	1.	.92	1.12	1.04	.78	.91	.61	.35	1.13	.6	.12	3.4	71	2.0	42	81	82	1.01
Mean of 8 curves				5.8	4.1	1.98	1.06									.10		68		.37	86	88	1.00

Vertical velocity measurements—Continued.

CHIPPEWA RIVER AT EAU CLAIRE, WIS.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 25	4.82	3.92	130	14.3	13.2	1.10	0.52	0.72	0.53	0.47	0.50	0.18	0.13	0.73	2.6	0.19	10.4	0.77	6.2	0.47	0.71	0.72	1.04
			150	13.5	12.4	1.10	.76	.90	.67	.83	.75	39	.58	.92	3.6	.28	11.3	.91	7.8	.63	.83	.84	1.01
			170	12.6	11.5	1.10	1.14	1.38	1.10	1.18	1.14	.40	.54	1.39	2.7	.22	10.0	.83	6.5	.57	.82	.83	1.00
Mean of 3 curves				13.5	12.4	1.10	.81									.23		.84		.56	.79	.80	1.02

CONNECTICUT RIVER AT ORFORD, N. H.[b]

1903.																							
January 29	6.71	5.40	150	.....	6.6	.....	1.92	2.17	2.23	1.65	.94	1.22	1.08	2.27	0.5	0.08	5	0.68	2.0	0.30	0.84	0.88	0.99
	6.75	5.50	280	.....	9.8	.....	1.94	2.12	2.15	1.82	.98	1.13	1.32	2.21	1.0	.10	0	.71	3.0	.31	88	.92	.98
January 30	7.30	6.00	340	.....	6.2	.....	1.85	1.96	1.92	1.86	.89	1.22	1.58	1.97	.8	.13	5.0	.81	2.5	.40	94	.94	.98
February 7	7.38	6.05	90	.....	7.7	.....	1.58	1.91	1.56	62	.59	.76	.85	1.91	1.7	.22	6.2	.81	3.8	.49	83	.83	1.00
January 30	7.30	6.00	100	.....	6.3	.....	1.73	1.93	1.92	53	72	1.15	1.19	2.00	6	.10	2	.66	2.3	.37	86	.90	1.00
February 7	7.38	6.05	110	.....	7.2	.....	1.76	1.99	1.94	1.60	77	1.22	1.05	2.04	.6	.08	5.	71	2.7	.37	86	88	1.00
Mean of 6 curves	.....	.....	.....	.....	7.3	.....	1.80	.....	.....	.....	.....	.....	.....	.....	.....	.12	.....	73	.....	.37	87	.89	.99
1904.																							
February 1	4.15	2.45	130	3.8	2.0	2.00	.67	.72	86	52	.69	.50	.33	.87	.1	.05	1.2	.60	.3	.15	77	.93	.97
			140	3.9	2.1	2.00	.40	.42	60	22	.41	.48	.00	.61	.....	.....	1.2	.57	.3	.14	66	.95	.97
			150	5.3	3.5	2.00	1.23	1.33	1.48	00	1.24	1.09	.70	1.48	.1	.03	2.4	.68	.7	.20	83	.92	1.00
February 2	3.95	2.25	250	7.7	6.0	2.00	1.04	1.10	1.21	92	.96	.80	.61	1.21	.3	.05	3.5	.58	1.3	.22	86	.95	.98
			260	8.2	6.5	1.85	1.03	1.13	1.16	.92	1.04	.74	.52	1.18	.3	.05	2	.65	2.0	.31	87	91	.99
			270	8.1	6.4	1.95	1.11	1.17	1.20	1.03	1.12	.93	.82	1.22	.5	.08	3	.67	1.9	.30	91	.95	1.00
			280	7.4	5.8	1.85	1.10	1.20	1.22	.98	1.10	.85	.70	1.23	.3	.06	3.9	67	1.8	.31	89	.92	1.00
February 3	4.17	2.37	200	5.0	3.0	2.25	.61	.66	.78	.43	.60	.55	.20	.78	2	.06	1.8	60	.4	.13	78	.92	1.00
February 4	4.03	2.22	110	4.8	3.3	1.70	1.12	1.20	1.32	.92	1.12	1.13	.68	1.32	.....	.....	2.0	60	.8	.24	85	.93	1.00

[a] Gravel bed.

[b] Gravel [illegible]

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of mean velocity.		Depth of thirds of mean velocity.				Depth of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	Top.	Bottom.	Maximum.	$\frac{0.2+0.8}{2}$ depth.	Upper.		Lower.								
															In feet.	In per cent of depth.	In feet.	In per cent of depth.			In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1904.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																			
February 5	4.03	2.23	90	5.2	3.6	1.75	0.93	1.03	1.05	0.82	0.92	0.34	1.06	0.94	0.5	0.14	2.2	0.61	1.3	0.36	0.88	0.90	1.00
			100	5.2	2.4	1.95	.96	1.06	1.15	.78	.90	.45	1.15	.96	.6	.17	2.5	.63	1.6	25	.93	.93	1.00
			340	5.3	4.2	1.60	.85	1.02	.98	.77	.88	.00	1.02	.88	.5	.12	2.9	.69	1.7	40	.83	.83	.97
Mean of 12 curves				5.7	4.1	1.91	.92								.4	.07		63		25	.82	.92	.99
1905.																									
February 28	4.07	2.25	100	4.2	3.1	1.3	1.00	1.13	1.00	0.99	.58	.80	1.15		.6	.19	2.3	0.75	1.2	0.39	0.87	0.88	1.00
			110	5.0	3.5	1.8	.88	1.02	1.02	.89	.40	.40	1.07		4	.11	2.3	.68	1.2	34	.92	.86	1.00
			120	5.5	3.9	1.8	1.24	1.32	1.36	1.25	1.00	.93	1.38		2	.05	2.5	.64	1.1	26	.94	.90	.99
			130	5.2	3.5	1.9	1.12	1.27	1.34	1.12	.96	.57	1.37		2	.05	2.3	.63	1.2	34	.92	.88	1.00
			150	5.5	3.7	2.0	1.15	1.23	1.32	1.19	.97	.75	1.33		2	.05	2.3	.62	.9	25	.94	.84	1.00
			160	5.0	3.2	2.2	.93	1.04	1.10	.94	.73	.40	1.		2	.03	2.1	.66	.8	25	.94	.89	.98
			180	5.8	3.6	2.5	.69	.87	.71	.67	.33	.38	.88		1	.03	2.7	.75	1.6	45	.78	.79	.93
			200	6.7	4.7	2.3	1.13	1.28	1.10	1.13	.87	.69	1.29		2	.19	3.7	.79	1.7	57	.88	.88	1.00
			260	6.7	5.1	1.9	1.19	1.33	1.25	1.19	.82	.85	1.35		3	.21	3.7	.79	2.0	59	.90	.90	1.00
			280	6.7	3.9	2.0	.92	1.13	.97	.90	.80	.60	1.23		2	.16	3.7	.72	2.0	36	.95	.95	1.02
			330	5.5											2	.18	2.8	.73	1.4	36	.81	.75	1.02
Mean of 10 curves				5.5	3.8	1.96	1.02								.3	.08	2.8	.70		36	.84	.88	1.00
March 1	4.26	2.40	110	5.2	3.6	1.8	1.08	1.25	1.23	1.06	.92	.48	1.32		3	.08	2.3	.64	1.3	36	.82	.86	1.02
			160	5.7	4.0	1.9	1.28	1.48	1.39	1.27	1.02	.72	1.53		6	.15	2.8	.70	1.6	40	.84	.86	1.01
			180	5.7	3.9	2.1	1.14	1.36	1.33	1.15	.92	.53	1.41		3	.06	2.7	.69	1.4	36	.81	.84	.99
			200	4.5	2.2	2.6	.76	.83	.80	.76	.56	.56	1.03		3	.09	1.6	.73	.9	41	.92	.92	1.00
			250	3	5.3	2.3	.94	.96	1.07	.96	.88	.72	1.07		2	.04	2.9	.55	1.0	19	.88	.88	.98
			270	5.2	5.2	2.2	1.25	1.37	1.32	1.25	1.00	.92	1.35		6	.12	3.7	.71	2.1	40	.91	.91	1.00
			320	5.5	3.8	1.8	1.14	1.32	1.27	1.18	.93	.55	1.33		4	.10	2.7	.71	1.7	45	.86	.86	1.00
			340	5.6	4.8	1.1	.92	1.12	1.04	1.01	.61	.35	1.13		6	.12	3.4	.71	2.0	42	.81	.82	1.01
Mean of 8 curves				5.8	4.1	1.98	1.06									.10		68		37	.86	.88	1.00

Vertical velocity measurements—Continued.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8 \text{ depth.}}{2}$	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 8 [a]	6.84	5.51	60	5.9	4.6	1.45	0.95	1.03	1.09	0.85	0.97	0.89	0.34	1.10	0.1	0.02	3.0	0.67	1.1	0.25	0.86	0.92	0.97
			140	7.7	5.6	2.15	1.58	1.89	1.42	1.62	1.52	1.00	1.14	1.95	1.6	.29	4.6	.81	3.4	.59	.81	.84	1.04
			180	7.2	6.1	1.20	1.67	1.86	1.87	1.53	1.70	1.44	.80	1.92	.6	.09	4.4	.72	1.8	.29	.87	.90	.98
			220	7.2	6.0	1.30	1.44	1.63	1.65	1.23	1.44	1.32	.66	1.72	.4	.06	4.0	.68	1.9	.31	.84	.88	1.00
			260	7.5	6.3	1.30	1.37	1.57	1.53	1.21	1.37	1.03	.67	1.00	.6	.09	4.5	.71	2.3	.36	.86	.88	1.00
			300	8.9	7.3	1.90	1.06	1.14	1.07	1.08	1.08	.90	.63	1.15	1.3	.18	6.1	.84	3.4	.47	.92	.93	.99
			340	8.0	6.4	1.80	.63	.73	.66	.61	.64	.37	.37	.73	1.1	.17	5.0	.77	2.9	.45	.86	.86	.99
Mean of 7 curves				7.5	6.0	1.59	1.24									.13		.74		.39	.86	.89	1.00
February 15 [a]	6.80	5.90	60	6.0	4.5	1.40	1.09	1.32	1.09	1.03	1.06	.57	.75	1.34	.9	.20	3.4	.75	1.9	.42	.81	.83	1.03
			140	7.6	5.3	2.20	1.60	1.92	1.45	1.75	1.60	.92	.65	1.97	1.4	.27	4.5	.84	3.2	.60	.81	.83	1.00
			180	7.3	6.1	1.20	1.58	1.80	1.80	1.34	1.57	1.25	.96	1.86	.6	.09	4.0	.66	2.2	.36	.85	.88	1.00
			220	7.2	5.8	1.30	1.44	1.63	1.66	1.19	1.42	1.38	.73	1.69	.2	.03	3.8	.66	1.9	.33	.85	.88	1.01
			260	7.5	6.2	1.30	1.36	1.48	1.48	1.27	1.38	1.04	.98	1.54	.8	.13	4.4	.70	2.1	.34	.88	.92	.98
			300	8.8	7.1	2.00	1.12	1.21	1.14	1.14	1.14	.90	.79	1.21	1.2	.17	5.8	.82	3.5	.49	.92	.93	.98
			340	8.0	6.3	1.70	.62	.70	.64	.59	.62	.44	.38	.71	1.0	.16	4.8	.76	2.5	.40	.87	.88	1.00
Mean of 7 curves				7.5	5.9	1.73	1.26									.15		.74		.42	.86	.88	1.00
February 17 [a]	6.56	5.61	60	5.6	4.1	1.60	1.09	1.27	1.07	1.07	1.07	.87	.70	1.29	1.0	.24	3.2	.78	2.4	.57	.85	.86	1.02
			140	7.2	5.0	2.20	1.49	1.81	1.32	1.53	1.42	.95	1.05	1.84	1.5	.29	4.1	.83	2.8	.56	.81	.82	1.04
			180	7.1	5.8	1.30	1.57	1.73	1.73	1.39	1.56	1.38	1.03	1.80	.5	.09	3.9	.68	1.9	.33	.87	.90	1.00
			220	7.0	5.6	1.40	1.29	1.55	1.62	.98	1.30	1.12	.45	1.70	.3	.05	3.7	.66	1.8	.32	.76	.84	1.00
			260	7.4	6.0	1.45	1.34	1.53	1.46	1.19	1.32	1.19	.77	1.54	.6	.10	4.2	.70	2.5	.42	.87	.88	1.01
			300	8.7	7.0	1.90	1.07	1.18	1.12	1.03	1.08	.85	.80	1.20	1.0	.14	5.2	.75	2.9	.41	.89	.91	1.00
			340	7.8	6.0	1.85	.55	.63	.59	.52	.56	.49	.14	.63	.7	.12	4.7	.78	3.0	.50	.88	.88	.99
Mean of 7 curves				7.3	5.6	1.67	1.20									.15		.74		.44	.85	.87	1.01

[a] Ice rough.

CONNECTICUT RIVER AT ORFORD, N. H.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 14 [a]	6.00	4.56	60	4.9	3.5	1.50	1.01	1.24	1.06	0.94	1.00	0.91	0.25	1.25	0.4	0.13	2.7	0.77	1.8	0.51	0.81	0.82	1.01
			140	6.6	4.5	2.15	1.38	1.60	1.45	1.24	1.34	1.12	.88	1.63	.7	.16	3.2	.71	1.8	.40	.84	.86	1.02
			180	6.2	4.9	1.40	1.39	1.56	1.58	1.22	1.49	1.05	.87	1.66	.5	.10	3.2	.66	1.6	.33	.84	.89	1.09
			220	6.5	5.2	1.35	1.18	1.34	1.43	.95	1.19	.99	.60	1.48	.4	.07	3.3	.63	1.4	.27	.80	.88	.99
			260	6.7	5.3	1.50	1.24	1.38	1.37	1.08	1.22	1.28	.72	1.41	.....	.....	3.5	.66	1.8	.35	.88	.90	1.01
			300	8.1	6.3	1.95	1.02	1.18	1.10	.95	1.02	.83	.49	1.20	.8	.14	4.7	.75	2.6	.41	.85	.87	1.00
			340	7.0	5.	2.00	.56	.62	.60	.52	.56	.57	.31	.63	.....	.....	3.8	.73	2.5	.49	.89	.90	1.00
Mean of 7 curves				6.6	4.9	1.69	1.11	.....	.....	.....	.....	.....	.....	.....	.....	.09	.....	.70	.....	.39	.84	.88	1.00
March 15 [a]	5.59	4.15	60	4.6	3.2	1.50	1.01	1.20	1.17	.88	1.02	.90	.17	1.23	.2	.07	2.3	.72	1.2	.38	.82	.88	.99
			140	6.2	4.2	2.10	1.36	1.52	1.43	1.27	1.35	1.05	1.02	1.55	.6	.15	3.0	.72	1.6	.38	.88	.90	1.01
			180	6.0	4.6	1.50	1.36	1.50	1.45	1.23	1.34	1.33	.80	1.50	.2	.03	3.2	.71	1.8	.39	.90	.90	1.01
			220	6.1	4.7	1.45	1.12	1.27	1.35	.90	1.12	1.08	.55	1.38	.1	.02	3.0	.63	1.4	.31	.81	.88	1.00
			260	6.5	5.	1.50	1.22	1.37	1.35	1.08	1.22	1.12	.77	1.40	.4	.07	3.5	.68	1.8	.35	.87	.89	1.00
			300	7.5	5.7	1.90	.98	1.10	1.05	.90	.98	.86	.55	1.13	.7	.12	4.1	.72	2.1	.37	.86	.89	1.00
			340	6.7	4.8	2.00	.51	.58	.55	.47	.51	.43	.30	.60	.6	.12	3.4	.71	1.8	.38	.85	.88	1.00
Mean of 7 curves				6.2	4.6	1.71	1.08	.....	.....	.....	.....	.....	.....	.....	.....	.08	.....	.70	.....	.37	.86	.88	1.00

DES MOINES RIVER AT KEOSAUQUA, IOWA.[b]

1906.																							
January 13 [a]	2.45	2.10	50	4.2	3.7	0.5	1.19	1.32	1.33	1.07	1.20	1.08	0.60	1.37	0.2	0.05	2.6	0.70	1.2	0.32	0.87	0.90	0.99
			350	5.5	5.0	.5	1.86	2.35	1.79	1.87	1.83	.63	.95	2.35	1.0	.21	4.0	.80	2.5	.50	.79	.79	1.02
			380	5.6	5.1	.5	1.82	2.03	1.98	1.66	1.82	1.25	1.30	2.09	.7	.14	3.5	.69	1.8	.35	.87	.90	1.00
			410	6.3	5.8	.5	1.65	1.87	1.91	1.39	1.65	1.35	.92	1.97	.5	.09	3.8	.66	1.8	.32	.84	.88	1.00
			520	4.5	4.2	.3	1.38	1.52	1.41	1.38	1.38	1.15	.78	1.52	.8	.18	3.4	.81	2.2	.51	.91	.91	1.00
Mean of 5 curves				5.2	4.8	.46	1.58	.....	.....	.....	.....	.....	.....	.....	.....	.13	.....	.73	.....	.40	.86	.88	1.00

[a] Ice rough.

[b] Gravel bed.

Vertical velocity measurements—Continued.

ESOPUS CREEK AT KINGSTON, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reduction to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 4	5.28	.....	90	6.8	6.7	0.10	0.91	1.10	0.88	0.88	0.88	0.60	0.20	1.10	1.4	0.21	5.1	0.76	3.7	0.55	0.83	0.83	1.03
			100	5.0	4.9	.10	.98	1.08	1.03	.93	.98	.88	.10	1.08	.5	.10	3.6	.73	2.4	.49	.91	.91	1.00
Mean of 2 curves	.....	.....	.....	5.9	5.8	.10	.94	.....	.....	.....	.....	.....	.....	.....	.....	.16	.....	.74	.....	.52	.87	.87	1.02
1902.																							
January 9	6.54	.....	70	4.2	.....	(b)	1.28	1.50	1.43	1.13	1.28	1.05	.40	1.55	.4	.10	3.0	.71	1.5	.36	.83	.85	1.00
			80	6.8	6.6	.20	1.39	1.50	1.50	1.33	1.42	1.05	.90	1.53	.8	.11	4.8	.73	.8	.12	.91	.93	.98
			90	8.1	8.0	.10	1.15	1.33	1.38	.96	1.17	.90	.30	1.40	.4	.05	5.4	.68	2.3	.29	.82	.86	.98
			100	6.1	6.0	.10	1.20	1.32	1.28	1.18	1.23	.80	.50	1.32	1.0	.11	4.7	.78	2.4	.40	.91	.91	.98
Mean of 4 curves	.....	.....	.....	6.3	5.2	.10	1.25	.....	.....	.....	.....	.....	.....	.....	.....	.09	.....	.72	.....	.29	.87	.89	.98
December 11	6.6	.....	30	3.0	2.9	.10	.87	1.05	1.10	.82	.96	.25	.20	1.11	.2	.05	2.4	.82	.8	.26	.78	.83	.91
			40	4.0	3.9	.10	1.14	1.28	1.37	.93	1.15	.30	.55	1.40	.3	.08	2.7	.69	1.2	.31	.81	.89	.99
			50	3.2	3.1	.10	1.21	1.50	1.60	.83	1.22	.50	.00	1.65	.2	.06	2.0	.66	1.0	.32	.73	.80	.99
			60	3.8	3.7	.10	1.24	1.39	1.50	1.05	1.28	.50	.50	1.53	.3	.08	2.4	.65	1.1	.29	.81	.89	.97
			70	4.2	4.1	.10	1.28	1.42	1.55	.98	1.26	1.25	.60	1.55	.....	.....	2.6	.63	1.0	.24	.83	.90	1.02
			80	7.0	6.9	.10	1.27	1.48	1.53	1.13	1.33	.50	.00	1.55	.4	.06	5.1	.74	2.0	.29	.82	.86	.96
			90	8.0	7.9	.10	1.17	1.23	1.43	.91	1.17	1.00	.10	1.45	.2	.03	4.4	.56	2.1	.27	.80	.95	1.00
			100	6.2	6.1	.10	1.06	1.23	1.24	.91	1.08	.82	.30	1.28	.5	.08	4.1	.67	2.2	.36	.83	.86	.98
Mean of 8 curves	.....	.....	.....	4.9	4.8	.10	1.16	.....	.....	.....	.....	.....	.....	.....	.....	.06	.....	.68	.....	.29	.80	.87	.98
1903.																							
January 14	6.90	.....	55	3.5	2.9	.60	1.08	1.12	1.31	.97	1.14	.80	.40	1.32	.2	.07	1.7	.59	.8	.28	.82	.96	.95
			70	4.2	3.6	.60	1.08	1.22	1.30	.95	1.12	.96	.34	1.32	.2	.06	2.6	.72	1.0	.28	.82	.88	.96

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 12	5.75		110	4.9	4.4	0.50	2.23	3.02	2.31	2.04	2.18	0.63	1.06	3.08	0.8	0.18	3.3	0.75	2.0	0.44	0.72	0.74	1.02
			120	5.7	4.7	.40	1.66	2.34	1.08	2.04	1.56	.00	.96	2.48	1.4	.31	4.1	.87	2.8	.60	.67	.71	1.06
			130	5.3	4.9	.40	2.28	2.56	2.87	1.68	2.28	2.48	1.07	2.92	.0	.....	3.0	.61	1.3	.26	.78	.89	1.00
			140	4.2	3.8	.40	1.20	1.41	1.47	.93	1.20	1.24	.62	1.48	.0	.....	2.6	.67	1.1	.29	.82	.86	1.06
February 13	5.78	.....	110	5.1	4.6	.45	1.63	2.07	2.12	1.23	1.68	1.13	.10	2.26	.35	.08	3.2	.68	1.4	.30	.72	.79	.98
			115	5.0	4.5	.50	2.47	3.00	2.79	2.16	2.48	.34	1.61	3.27	.65	.14	3.1	.69	1.6	.36	.76	.82	1.00
			130	5.5	5.2	.30	2.06	2.29	2.74	1.42	2.08	2.57	.63	2.74	.....	.....	3.0	.59	1.2	.22	.75	.90	.99
			135	5.5	5.2	.30	1.70	2.01	2.07	1.25	1.66	1.86	.58	2.16	.....	.....	3.3	.64	2.0	.38	.79	.85	1.03
			140	4.5	4.2	.35	.88	1.22	1.10	57	.84	.94	.00	1.23	.....	.....	2.9	.70	1.9	.46	.72	.72	1.05
February 16	6.00		17	3.3	2.8	.55	.64	.68	.64	62	.63	.55	56	.68	.6	.21	2.0	.71	1.2	.43	.93	.94	1.01
			27	3.0	2.4	.60	1.15	1.38	1.34	99	1.16	.85	72	1.45	.2	.10	1.7	.69	.9	.37	.79	.83	.99
			37	3.1	2.6	.60	1.63	1.83	1.79	1.41	1.60	1.49	98	1.88	.2	.08	1.7	.68	1.0	.37	.87	.89	1.02
			47	3.5	3.0	.60	1.92	2.22	2.18	1.71	1.94	1.56	1.20	2.34	.3	.09	2.1	.70	.9	.32	.82	.87	.99
			57	3.5	2.9	.60	1.99	2.19	2.34	1.66	2.00	1.90	1.22	2.34	.05	.02	1.9	.66	.6	.19	.85	.91	1.00
			67	3.6	3.0	.60	2.06	2.30	2.34	1.79	2.06	1.89	1.40	2.37	.2	.05	2.0	.66	.9	.30	.87	.89	1.00
			77	4.4	3.8	.60	1.95	2.13	2.28	1.61	1.94	1.93	1.28	2.32	.0	.....	2.4	.61	1.2	.31	.84	.92	1.00
			87	4.9	4.4	.60	1.84	2.14	2.02	1.55	1.78	1.50	1.11	2.17	.4	.10	2.8	.64	1.8	.40	.85	.86	1.03
			97	4.7	4.2	.80	1.46	1.65	1.71	1.20	1.46	.87	90	1.78	.2	.06	2.6	.62	1.8	.45	.82	.89	1.01
			107	4.0	3.4	.80	1.04	1.11	1.20	93	1.06	.78	78	1.21	.2	.04	2.1	.61	.7	.20	.86	.93	.97
			117	2.8	2.2	.80	.59	.72	.76	47	.62	.74	03	.76	.....	.....	1.6	.70	.6	.18	.78	.82	.96
Mean of 20 curves			.....	8.6	3.8	.54	1.62	.....	.....	.....	.....	.....	.....	.....	.....	.07	.....	.67	.....	.34	.80	.85	1.01
February 12[b]	5.75	.....	90	3.8	2.4	.60	.98	1.54	1.22	1.46	1.34	.0	1.21	1.56	.2	.06	.....	.....	1.3	.54	.63	.64	.73
			100	4.9	3.6	.45	1.98	3.20	2.10	2.64	1.42	.0	1.76	3.23	.6	.02	3.5	.97	2.0	.56	.61	.62	1.39
February 13[b]	5.78	.....	90	3.9	2.8	.60	1.14	1.66	1.14	1.48	.98	.0	1.08	1.67	.6	.19	2.8	.98	1.6	.56	.68	.69	.86
			95	4.1	3.2	.30	1.62	2.26	1.26	2.45	1.44	.0	2.26	2.46	1.8	.57	.....	.....	2.2	.69	.66	.72	1.12
			100	4.6	4.2	.40	2.36	3.25	1.56	2.95	2.26	.0	1.89	3.36	1.3	.31	3.9	.93	2.5	.60	.70	.73	1.04
			105	5.4	5.0	.40	2.18	3.23	1.32	2.58	1.95	.16	1.62	3.25	1.7	.34	4.4	.88	2.6	.51	.67	.68	1.12
			125	5.1	4.2	.30	2.35	3.06	2.94	2.49	2.60	.0	1.66	3.06	.2	.04	3.5	.83	1.8	.43	.77	.77	.90
Mean of 7 curves			.....	4.5	3.6	.44	1.80	.....	.....	.....	.....	.....	.....	.....	.....	.22	.....	.66	.....	.56	.68	.69	1.02

[a] Coarse gravel bed.

[b] Needle ice.

Vertical velocity measurements—Continued.

FISH RIVER AT WALLAGRASS, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 15	3.91	3.25	90	3.2	1.7	1.5	0.87	0.98	0.93	0.77	0.85	0.83	0.62	0.97	0.1	0.06	1.2	0.68	0.6	0.35	0.90	0.89	1.02
			110	4.5	3.3	1.2	1.18	1.30	1.24	1.13	1.18	1.03	.76	1.30	.4	.12	2.5	.76	1.6	.50	.91	.91	1.00
			130	4.8	3.6	1.2	1.03	1.17	1.17	.93	1.05	.76	.50	1.20	.4	.10	2.6	.72	1.3	.36	.86	.88	.98
			150	3.0	1.3	1.7	.55	.58	.60	.49	.54	.57	.42	.60	.0	.00	.8	.62	.3	.23	.91	.95	1.00
Mean of 4 curves				3.9	2.5	1.40	.91									.07		.70		.36	.89	.90	1.00
March 15	4.99	3.83	90	4.3	2.9	1.4	1.22	1.45	1.28	1.15	1.22	.70	.74	1.45	.5	.16	2.2	.76	1.3	.45	.84	.84	1.01
			110	5.6	4.3	1.3	1.50	1.74	1.42	1.62	1.52	.73	1.06	1.79	1.0	.24	3.6	.85	2.7	.63	.84	.86	.98
			130	5.9	4.6	1.3	1.39	1.70	1.53	1.43	1.48	.43	.35	1.71	.8	.16	3.8	.82	1.9	.41	.81	.82	.94
			150	4.1	2.3	1.8	.88	.95	1.01	.78	.90	.90	.45	1.01			1.5	.64	.5	.22	.87	.92	.98
Mean of 4 curves				5.0	3.5	1.45	1.25									.14		.77		.43	.84	.86	.98
March 15	5.08	3.92	90	4.4	3.0	1.4	1.24	1.44	1.33	1.17	1.25	.70	.80	1.45	.5	.16	2.2	.75	1.4	.47	.86	.86	.99
			110	5.6	4.3	1.3	1.52	1.76	1.46	1.62	1.54	.77	1.07	1.79	1.0	.22	3.6	.85	2.7	.63	.85	.86	.99
			130	6.0	4.7	1.3	1.40	1.70	1.56	1.42	1.49	.44	.34	1.72	.7	.15	3.8	.81	1.8	.38	.81	.82	.94
			150	4.3	2.5	1.8	.87	.95	1.04	.74	.89	.92	.35	1.04			1.6	.66	.6	.24	.84	.92	.98
Mean of 4 curves				5.1	3.6	1.45	1.26									.13		.77		.43	.84	.87	.97

FLAMBEAU RIVER AT LADYSMITH, WIS.[a]

1906.																							
January 26	16.13	15.33	120	4.0	3.1	0.9	1.68	1.77	1.90	1.44	1.67	1.88	1.05	1.90			1.9	0.61	0.4	0.13	0.88	0.95	1.00
			140	3.3	2.3	1.0	1.62	1.71	1.79	1.46	1.62	1.78	1.12	1.79			1.5	.65	.3	.13	.90	.95	1.00

Vertical velocity measurements—Continued.

GENESEE RIVER ONE-FOURTH MILE ABOVE ELMWOOD AVENUE BRIDGE, ROCHESTER, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of thread of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet*																	
February 14	1.42	.....	40	7.9	7.4	0.50	0.40	0.46	0.45	0.36	0.40	0.34	0.22	0.50	0.8	0.11	5.0	0.68	3.1	0.42	0.81	0.88	1.00
			60	8.0	7.5	.50	.43	.52	.50	.46	.48	.36	.06	.52	.4	.05	5.5	.73	3.1	.41	.83	83	.90
			80	7.1	6.6	.45	.46	.52	.56	.34	.45	.28	.16	.58	.4	.07	4.2	.63	1.7	.26	.79	88	1.01
			100	7.7	7.3	.40	.42	.45	.44	.42	.43	.40	.24	.45	.6	.08	5.9	.81	4.8	.66	.94	94	.99
			120	7.7	7.3	.40	.52	.58	.54	.50	.52	.32	.38	.58	1.0	.14	5.8	.79	3.3	.45	.89	89	1.00
			140	8.1	7.7	.40	.46	.50	.44	.45	.44	.23	.32	.51	1.5	.19	6.4	.83	4.3	.56	.91	92	1.04
			160	7.4	7.0	.40	.49	.58	.50	.48	.49	.25	.18	.58	1.0	.14	5.7	.81	3.6	.51	.84	84	.99
			180	7.1	6.7	.40	.46	.56	.53	.47	.50	.36	.00	.56	.5	.08	5.4	.81	3.1	.46	.83	83	.93
			200	6.4	5.9	.50	.42	.52	.55	.26	.40	.48	.00	.55	.0	.00	4.0	.68	1.5	.25	.77	81	1.04
			220	5.4	4.9	.50	.48	.55	.48	.48	.48	.30	.25	.55	.9	.08	4.0	.41	3.0	.31	.87	87	1.00
			240	5.2	4.7	.50	.40	.50	.45	.38	.42	.36	.00	.50	.4	.08	3.7	.79	2.5	.53	.81	81	.98
Mean of 11 curves	.....	.....	.....	7.1	6.6	.45	.45	.....	.....	.....	.....	.....	.....	.....	.....	.09	.....	.72	.....	.44	.84	86	.99

HOOSIC RIVER AT BUSKIRK, N. Y.[b]

1906.																							
February 10[c]	3.90	.....	60	4.6	4.2	0.35	0.90	1.38	1.03	1.40	1.21	0.0	1.35	1.40	0.4	0.11	0.0	.....	2.0	0.47	0.64	0.65	0.75
			70	5.5	5.1	.40	1.80	2.06	1.58	2.15	1.86	.0	2.15	2.15	1.2	.23	.....	.....	4.0	.78	.84	.88	.97
			80	6.9	6.4	.45	1.81	2.52	2.15	2.30	2.22	.0	1.95	2.53	.8	.12	.....	.....	2.7	.42	.72	.72	.81
			90	8.1	7.6	.45	1.54	2.75	2.25	2.10	2.18	.0	1.10	2.75	.6	.08	5.2	0.68	2.9	.38	.56	.56	.71
			100	7.5	7.0	.45	1.64	2.68	1.35	2.30	1.82	.0	1.00	2.80	1.6	.22	5.6	.79	3.7	.52	.59	.61	.90
			110	6.6	6.2	.45	.81	2.16	2.06	1.68	1.87	.0	1.12	2.23	.0	.....	.....	.....	1.0	.16	.56	.38	.43
Mean of 6 curves	.....	.....	.....	6.6	6.1	.38	1.57	.....	.....	.....	.....	.....	.....	.....	.....	.13	.....	.24	.....	.45	.62	.63	.76

[a] Coarse gravel bed.

[b] Gravel bed.

[c] More or less needle ice under ice surface on all of these curves.

Vertical velocity measurements—Continued.

GENESEE RIVER AT ELMWOOD AVENUE BRIDGE, ROCHESTER, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 15	1.55	.....	40	4.2	3.9	0.3	0.92	1.04	1.08	0.76	0.92	1.05	0.26	1.10	.....	.....	2.7	0.69	1.2	0.31	0.84	0.89	1.00
			50	4.3	4.0	.3	.89	1.04	1.08	.72	.90	1.05	.10	1.10	.....	.....	2.8	.70	1.2	.30	.81	.86	.99
			60	4.5	4.2	.3	1.06	1.18	1.18	.98	1.08	1.12	.48	1.20	.....	.....	3.1	.74	1.5	.36	.89	.90	.99
			70	5.1	4.8	.3	.92	1.17	1.20	.60	.90	1.10	.00	1.23	.....	.....	3.4	.71	1.6	.33	.75	.78	1.02
			80	3.7	3.4	.3	1.24	1.35	1.28	1.18	1.23	1.04	.95	1.35	0.5	0.02	2.6	.76	1.5	.44	.91	.92	1.01
			90	3.8	3.5	.3	1.00	1.30	1.33	.66	1.00	1.24	.00	1.36	.....	.....	2.4	.68	1.4	.40	.74	.77	1.01
			100	3.5	3.0	.45	1.23	1.40	1.36	1.04	1.20	1.25	.65	1.40	.....	.....	2.2	.72	1.4	.46	.88	.88	1.03
			110	4.3	3.8	.5	1.20	1.34	1.36	1.03	1.20	1.15	.70	1.40	.....	.....	2.6	.68	1.2	.32	.86	.90	1.01
			120	4.2	3.7	.5	.93	1.05	1.24	.65	.94	1.20	.20	1.24	.....	.....	2.3	.62	.6	.16	.75	.89	.99
			140	3.0	2.5	.5	.83	1.00	1.10	.55	.82	1.04	.10	1.10	.....	.....	1.6	.64	.6	.24	.75	.83	1.00
			150	4.6	4.1	.5	.88	1.14	1.08	.72	.90	.86	.00	1.15	.....	.....	3.0	.74	1.8	.44	.76	.77	.98
			160	4.3	3.8	.5	.69	.76	.78	.66	.72	.68	.40	.80	.....	.....	3.0	.79	1.0	.26	.86	.91	.96
			170	4.5	4.0	.5	.82	.86	.88	.75	.82	.74	.66	.90	.1	.02	3.0	.74	1.2	.30	.91	.95	1.00
			180	5.0	4.5	.5	.76	.80	.80	.64	.72	.82	.25	.80	.....	.....	3.0	.67	1.9	.42	.95	.95	1.05
			190	5.0	4.5	.5	.73	.76	.90	.52	.71	.75	.33	.90	.....	.....	2.5	.56	.8	.18	.82	.97	1.03
			200	4.1	4.6	.5	.86	.92	.85	.81	.83	.60	.66	.92	.7	.02	2.7	.58	1.6	.35	.93	.93	1.04
			210	4.3	3.8	.5	.70	.80	.86	.63	.74	.74	.30	.86	.....	.....	2.7	.71	.8	.21	.82	.88	.94
			220	4.3	3.8	.5	.68	.82	.82	.58	.70	.68	.35	.85	.....	.....	2.7	.72	1.2	.30	.80	.83	.98
			230	3.3	2.9	.5	.50	.74	.50	.46	.48	.12	.10	.74	.6	.21	2.2	.77	1.5	.51	.68	.68	1.05
Mean of 19 curves				4.4	3.8	.43	.89	.....	.....	.....	.....	.....	.....	.....	.....	.01	.....	.70	.....	.33	.82	.87	1.00

[a] Coarse gravel bed.

Vertical velocity measurements—Continued.

GENESEE RIVER ONE-FOURTH MILE ABOVE ELMWOOD AVENUE BRIDGE, ROCHESTER, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 14	1.42	.....	40	7.9	7.4	0.50	0.40	0.46	0.45	0.36	0.40	0.34	0.22	0.50	0.8	0.11	5.0	0.68	3.1	0.42	0.81	0.88	1.00
			60	8.0	7.5	.50	.43	.52	.50	.46	.48	.36	06	.52	.4	.05	5.5	.73	3.1	.41	.83	.83	.90
			80	7.1	6.6	.45	.46	.52	.56	.34	.45	.28	16	.58	.4	.07	4.2	.63	1.7	.26	.79	.88	1.01
			100	7.7	7.3	.40	.42	.45	.44	.42	.43	.40	24	.45	.6	.08	5.9	.81	4.8	.66	94	.94	.99
			120	7.7		.40	.52	.58	.54	.50	.52	.32	38	.58	1.0	.14	5.8	.79	3.3	.45	89	.89	1.00
			140	8.1		.40	.46	.50	.44	.45	.44	.23	32	.51	1.5	.19	6.4	.83	4.3	.56	91	.92	1.04
			160	7.4	0	.40	.49	.58	.50	.48	.49	.25	18	.58	1.0	.14	5.7	.81	3.6	.51	84	.84	.99
			180	7.1	6.7	.40	.46	.56	.53	.47	.50	.36	00	.56	.5	.08	5.4	.81	3.1	.46	83	.83	.93
			200	6.4	5.9	.50	.42	.52	.55	.26	.40	.48	00	.55	.0	.00	4.0	.68	1.5	.25	77	.81	1.04
			220	5.4	4.9	.50	.48	.55	.48	.48	.48	.30	25	.55	.9	.08	4.0	.41	3.0	.31	87	.87	1.00
			240	5.2	4.7	.50	.40	.50	.45	.38	.42	.36	.00	.50	.4	.08	3.7	.79	2.5	.53	81	.81	.98
Mean of 11 curves	.....	.....	.....	7.1	6.6	.45	.45	.....	.....	.....	.....	.....	.....	.....	.....	.09	.....	.72	.....	.44	84	.86	.99

HOOSIC RIVER AT BUSKIRK, N. Y.[b]

1906.																							
February 10[c]	3.90	.....	60	4.6	4.2	0.35	0.90	1.38	1.03	1.40	1.21	0.0	1.35	1.40	0.4	0.11	0.0	.....	2.0	0.47	0.64	0.65	0.75
			70	5.5	5.1	.40	1.80	2.06	1.58	2.15	1.86	.0	2.15	2.15	1.2	.23	.....	.....	4.0	.78	.84	.88	.97
			80	6.9	6.4	.45	1.81	2.52	2.15	2.30	2.22	.0	1.95	2.53	.8	.12	.....	.....	2.7	.42	.72	.72	.81
			90	8.1	7.6	.45	1.54	2.75	2.25	2.10	2.18	.0	1.10	2.75	.6	.08	5.2	0.68	2.9	.38	.56	.56	.71
			100	7.5	7.0	.45	1.64	2.68	1.35	2.30	1.82	.0	1.00	2.80	1.6	.22	5.6	.79	3.7	.52	.59	.61	.90
			110	6.6	6.2	.45	.81	2.16	2.06	1.68	1.87	.0	1.12	2.23	.0	.....	.....	.....	1.0	.16	.56	.38	.43
Mean of 6 curves	.....	.....	.....	6.6	6.1	.38	1.57	.....	.....	.....	.....	.....	.....	.....	.....	.13	.....	.24	.....	.45	.62	.63	.76

[a] Coarse gravel bed. [b] Gravel bed. [c] More or less needle ice under ice surface on all of these curves.

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.			
1904.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 2	3.55	±1.45	50	.....	0.9	1.9	1.78	1.97	1.95	1.56	1.75	1.80	1.16	2.00	0.0	0.00	0.6	0.67	0.	0.44	0.89	0.90	1.02
			60	.....	1.1	1.8	1.84	2.09	1.78	1.89	1.83	1.32	1.40	2.10	.2	.18	.9	.82	.6	.55	.88	.88	1.00
			70	.....	1.1	2.0	1.66	1.89	1.84	1.43	1.63	1.60	1.00	1.92	.1	.09	.7	.63	.4	.36	.86	.88	1.02
			80	.....	1.6	1.9	1.77	2.24	1.65	1.78	1.72	1.08	1.08	2.24	.4	.25	1.3	.81	.8	.50	.79	.79	.98
			90	.....	1.9	2.0	2.26	2.76	2.30	2.20	2.25	1.76	1.30	2.77	.4	.21	1.5	.79	9	.47	.81	.82	1.00
			100	.....	2.2	2.0	2.29	2.76	2.60	1.98	2.29	1.80	.98	2.84	2	.09	1.6	.73	.8	.36	.81	.83	1.00
			110	.....	2.3	2.1	2.44	2.93	2.60	2.30	2.45	1.36	1.65	2.98	4	.17	1.7	.74	1.0	43	.82	.83	1.00
			120	.....	2.2	2.4	2.25	3.10	2.18	2.42	2.30	.20	1.04	3.10	5	.23	1.8	.82	1.1	50	.73	.74	.98
			130	.....	2.0	2.4	2.11	2.62	2.20	2.06	2.13	.82	1.32	2.66	4	.20	1.6	.80	.8	40	.79	.81	.99
			140	.....	1.8	2.2	2.06	2.64	2.11	1.91	2.01	.92	1.26	2.72	4	.22	1.3	.72	.7	39	76	78	1.02
			150	.....	1.7	2.3	1.92	2.45	2.10	1.85	1.97	1.14	.70	2.46	3	.18	1.3	.77	.8	47	78	80	.98
			160	.....	.4	2.3	1.75	2.16	1.70	1.72	1.71	.88	1.30	2.20	3	.21	1.1	.79	.6	43	80	82	1.02
			170	.....	.5	2.1	1.62	1.98	1.55	1.63	1.59	.80	1.20	2.00	3	.20	1.2	.80	.6	40	81	71	1.02
			180	.....		2.4	1.25	1.60	1.12	1.30	1.21	.56	.84	1.62	3	.27	.9	.82	.6	.55	77	78	1.04
			190	.....	.9	2.4	1.13	1.30	1.11	1.09	1.10	.90	.84	1.30	2	.22	.7	.78	.4	.44	87	87	1.02
Mean of 15 curves			...	...	.6	2.15	1.87	.....	.....	.....	.....	.....	.....	.....	.....	.18	.....	.77	.....	.45	81	82	1.01
January 27	3.40	1.55	100	...	2.5	.....	2.18	2.38	2.59	1.72	2.15	2.40	1.00	2.60	.....	.....	1.5	.60	7	28	84	91	1.02
			10	...	2.7	.....	2.22	2.38	2.70	1.75	2.22	2.60	1.03	2.72	.....	.....	2.0	.74	3	11	82	93	1.00
			120	...	3.0	.....	2.30	2.47	2.94	1.67	2.30	2.75	.86	2.94	.....	.....	1.7	.57	6	20	78	93	1.00
			130	...	2.7	.....	2.38	2.60	2.92	1.82	2.37	2.83	.95	2.93	.....	.....	1.6	.59	4	15	81	92	1.00
Mean of 4 curves	.....	.....	...	...	2.7	.....	2.27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.63	.....	19	82	92	1.00
1905.																							
February 9	5.27	3.27	10½	3.2	1.3	1.9	1.06	1.16	1.06	1.06	1.06	.62	.85	1.17	.2	.15	1.06	.77	6	46	91	.92	1.00
			31	3.8	1.8	2.0	1.36	1.60	1.62	1.04	1.33	1.22	.57	1.67	.1	.05	1.2	.67	3	28	81	.85	1.02
			50	4.	2.1	2.0	1.92	2.08	2.23	1.63	1.93	1.66	1.25	2.27	.0	.00	1.3	.62	0	29	85	.93	1.00
			71½	5.2	3.2	2.1	2.00	2.27	[illegible]	[illegible]	[illegible]	1.45	.02	2.41	.1	.03	2.1	.66	1.0	31	83	.88	1.00
			92	6.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.60	1.45	2.63	.5	.12	2.8	.67	1.	.96	85	88	1.01

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 9	5.27	3.27	112	6.1	4.2	1.9	2.36	2.74	2.62	2.08	2.35	1.60	1.40	2.80	0.5	0.12	2.9	0.69	1.5	0.36	0.84	0.86	1.00
			134	6.	4.2	1.9	2.47	2.77	2.59	2.29	2.44	2.02	1.40	2.78	.5	.12	3.2	.76	2.1	.50	.89	.89	1.01
			154	6.0	4.0	2.0	2.32	2.57	2.58	2.10	2.34	1.00	1.72	2.69	.4	.10	2.7	.68	1.3	.32	.86	.90	.99
			173	6.0	4.0	2.0	2.18	2.50	2.34	2.00	2.17	.57	1.34	2.52	.5	.13	2.9	.72	1.8	.45	.86	.88	1.00
			194	6.0	3.9	2.0	1.57	1.98	1.44	1.74	1.58	.45	.60	1.98	.9	.23	3.3	.85	2.2	.56	.79	.79	.99
			216	6.3	4.1	2.2	.89	1.04	.86	.87	.88	.62	.45	1.04	1.2	.30	3.0	.73	2.3	.56	.86	.86	1.01
Mean of 11 curves				5.4	3.4	2.00	1.85									.12		.71		.40	.85	.88	1.00
February 9	5.32	3.32	10½	3.2	1.3	1.9	1.25	1.48	1.34	1.07	1.20	.00	.61	1.50	.2	15	1.0	.77	.6	.46	.83	.85	1.04
			31	3.9	1.9	2.0	1.50	1.62	1.67	1.31	1.48	1.35	1.08	1.72	.1	05	1.2	.63	.6	.31	.87	.93	1.01
			71½	5.2	3.2	2.1	2.02	2.44	2.36	1.58	1.97	1.82	.62	2.49	.1	03	2.1	.66	1.3	.41	.81	.83	1.03
			112	6.2	4.2	1.9	2.42	2.72	2.74	2.07	2.41	1.95	1.35	2.80	.2	05	2.9	.69	1.5	.36	.86	.89	1.00
			154	6.0	4.0	2.0	2.33	2.52	2.58	2.10	2.34	2.03	1.60	2.65	.3	08	2.6	.65	1.2	.30	.88	.93	1.00
			194	6.1	3.9	2.0	1.63	1.87	1.64	1.61	1.62	1.08	1.00	1.88	.7	18	3.0	.77	2.2	.56	.87	.87	1.00
			236	7.0	4.7	2.1	1.37	1.58	1.32	1.38	1.34	.94	.85	1.60	1.2	25	3.8	.81	2.7	.57	.86	.87	1.02
			279	5.5	3.3	2.0	1.15	1.48	.72	1.52	1.12	.10	1.03	1.63	1.2	36	3.1	.94	2.1	.64	.71	.78	1.03
			320	4.4	2.3	2.1	.70	.85	.78	.58	.68	.61	.14	.86	.1	04	1.6	.70	1.0	.44	.81	.83	1.03
			361	3.7	1.6	2.1	.99	1.15	1.28	.67	.98	1.20	.10	1.30			1.0	.63	.4	.25	.76	.86	1.01
			409	4.5	2.6	1.9	.66	.90	.57	.67	.62	.25	.00	.96	.1	04	1.3	.50	1.6	.62	.69	.74	1.06
			448	4.5	2.5	2.0	.41	.48	.43	.35	.39	.30	.20	.51	.6	24	1.5	.60	1.0	.40	.80	.85	1.05
Mean of 12 curves				5.0	3.0	2.01	1.37									12		.70		.44	.81	.85	1.02
1906.																							
January 10	3.40	2.05	90	4.0	2.8	1.3	1.40	1.53	1.58	1.18	1.38	1.35	85	.60	.1	04	1.8	.65	.8	.29	.87	.91	1.01
			130	5.0	3.7	1.4	1.55	1.99	1.73	1.34	1.54	1.42	95	1.75	.2	04	2.5	.68	1.0	.28	.88	.92	1.01
			290	4.4	3.2	1.3	1.45	1.55	1.62	1.29	1.46	1.42	97	1.62	.1	02	2.1	.66	.8	.26	.90	.94	1.00
			330	3.1	2.1	1.1	1.23	1.31	1.37	1.07	1.22	1.27	81	1.37			1.3	.64	.5	.23	.90	.94	1.01
			370	2.6	1.5	1.3	.74	.88	93	.52	72	78	19	.95			1.0	.65	.4	.30	.78	.84	1.02
			410	2.9	1.8	1.3	.58	.68	66	.46	56	53	25	71	.1	07	1.2	.67	.7	.38	.82	.85	1.04
Mean of 6 curves				3.7	2.5	1.28	1.16									03		.66		.29	.86	.90	1.02

Vertical velocity measurements—Continued.

KENNEBEC RIVER AT NORTH ANSON, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 10	3.56	2.21	90	4.2	3.1	1.2	1.35	1.52	1.51	1.13	1.32	1.24	0.77	1.59	0.2	0.06	2.1	0.68	0	0.32	0.85	0.89	1.02
			130	5.1	3.7	1.5	1.65	1.74	1.78	1.50	1.64	1.50	1.25	1.82	.2	07	2.3	63	2	.32	.91	.95	1.01
			290	4.6	3.4	1.3	1.45	1.59	1.60	1.29	1.44	1.32	.93	1.64	.3	08	2.3	68		.32	.89	.92	1.01
			330	3.3	2.2	1.2	1.21	1.31	1.36	1.03	1.20	1.22	.71	1.37	.....		1.4	65	6	.26	.88	.92	1.01
			370	2.7	1.6	1.3	.78	.87	.85	.65	.75	.73	.51	.90	.1	08	1.0	64	6	.38	.86	.89	1.04
			410	3.1	1.9	1.4	.64	.70	.75	.52	.64	.64	.36	.77	.0	00	1.2	61	5	.26	.84	.92	1.02
Mean of 6 curves				3.8	2.6	32	1.18									05		65		.31	.87	.92	1.02
March 2	4.26	2.43	70	3.3	1.8	1.	1.48	1.72	1.62	1.34	1.48	1.33	.40	1.72	.2	09	1.3	73	8	47	.86	.86	1.00
			90	4.9	3.3	1.	1.67	1.85	1.84	1.56	1.70	1.42	.75	1.92	.3	09	2.4	73		.33	.87	.90	.98
			130	5.9	3.9	2.	1.94	2.15	2.18	1.70	1.94	1.97	1.14	2.20	.....		2.6	67	3	.33	.88	.90	1.00
			170	5.5	3.7		1.71	1.92	1.97	1.52	1.74	1.39	.94	2.00	3	08	2.6	69	1.1	.30	.86	89	98
			210	4.7	3.0		1.15	1.30	1.34	1.01	1.18	.75	.66	1.38	3	09	2.0	68	9	.30	.83	88	.98
			290	5.3	3.4	2.	1.58	1.73	1.77	1.43	1.60	1.27	1.10	1.79	3	08	2.3	68	0	28	88	91	.98
			330	4.1	2.3	1.	1.40	1.53	1.58	1.23	1.40	1.15	.92	1.61	2	07	1.5	66	7	.30	87	91	.99
			370	3.5	1.7	2.0	1.05	1.19	1.21	.87	1.04	1.00	.52	1.27		04	1.1	66	6	.32	82	88	1.00
			410	3.8	1.9	2.0	.90	1.00	1.07	.73	.90	.93	.50	1.07			1.2	63	5	.26	84	90	1.00
			450	3.3	1.5	2.0	.68	.74	.73	.65	.69	.68	.30	.74	0	00	1.1	75	6	40	92	92	.99
Mean of 10 curves				4.4	2.6	1.90	1.35									05		69		33	86	90	.99
March 3	4.08	2.27	70	3.1	1.6	1.7	1.38	1.55	1.50	1.23	1.36	1.14	.97	1.63	2	12	1.1	.68	6	.37	84	.89	1.01
			130	5.7	3.7	2.0	1.86	1.99	2.09	1.63	1.86	1.78	1.30	2.10		03	2.3	.63	1.0	27	88	.93	1.00
			170	5.3	3.5	2.0	1.68	1.83	1.89	1.54	1.72	1.48	.90	1.90	2	05	2.5	71	9	26	88	.92	.98
			210	4.5	2.8	1.9	1.06	1.23	1.23	.92	1.08	.86	.48	1.28	2	07	2.0	70	9	32	83	.86	.99
			290	5.0	3.1	2.0	1.43	1.57	1.64	1.28	1.46	.95	.95	1.66		08	2.1	.67	9	29	.86	.91	.98
			330	3.8	2.1	1.8	1.31	1.42	1.38	1.23	1.30	1.14	1.00	1.44		13	1.5	.70	.8	38	.91	.92	1.00

KENNEBEC RIVER AT NORTH ANSON, ME.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8 \text{ depth.}}{2}$	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 30	4.77		90	5.5	3.5	2.2	1.53	1.78	1.72	1.36	1.54	1.18	0.80	1.82	0.4	0.12	2.5	0.72	1.3	0.37	0.84	0.86	1.00
			130	6.3	4.1	2.3	2.00	2.23	2.25	1.76	2.00	1.67	1.26	2.29	.3	.07	2.8	.68	1.5	.36	.88	.90	1.00
			170	6.0	3.9	2.3	1.74	1.99	1.98	1.50	1.74	1.55	.88	2.06	.3	.08	2.7	.69	1.4	.36	.84	.87	1.00
			210	5.1	3.0	2.3	1.21	1.36	1.39	1.12	1.26	.69	.85	1.42	.3	.11	2.1	.70	.8	.28	.85	.89	.96
			290	5.7	3.4	2.5	1.52	1.63	1.72	1.39	1.56	1.15	1.12	1.72	.3	.08	2.2	.66	.8	.24	.88	.93	.98
			330	4.6	2.4	2.3	1.39	1.49	1.47	1.30	1.38	1.40	.89	1.50			1.7	.71	.9	.38	.93	.93	1.00
			370	4.0	1.8	2.4	1.04	1.19	1.23	.96	1.10	.59	.53	1.25	.2	.10	1.3	.72	.4	.25	.84	.88	.95
			410	4.1	1.9	2.4	.93	1.02	1.03	.84	.94	.89	.60	1.04	.1	.05	1.3	.68	.6	.34	.90	.91	1.00
			450	4.0	1.8	2.4	.61	.70	.69	.56	.62	.48	.36	.73	.2	.09	1.3	.72	.6	.30	.84	.87	.98
Mean of 9 curves				5.0	2.9	2.34	1.33									.08		.70		.32	.87	.90	.98
April 11	4.70	2.80	90	5.4	3.6	1.8	1.50	1.81	1.50	1.50	1.50	.75	.90	1.82	.7	.20	2.9	.80	1.7	.47	.83	.83	1.00
			130	6.3	4.3	2.0	1.90	2.14	2.00	1.84	1.92	1.30	1.22	2.16	.6	.15	3.4	.80	1.7	.40	.88	.89	.99
			170	5.9	3.9	2.0	1.74	1.96	1.92	1.50	1.71	1.50	1.15	2.03	.4	.09	2.6	.66	1.5	.38	.85	.89	1.01
			210	5.1	3.2	1.9	1.25	1.42	1.34	1.15	1.24	1.00	.75	1.45	.4	.13	2.3	.71	1.2	.37	.86	.88	1.00
			250	5.6	3.2	2.4	1.10	1.22	1.19	1.01	1.10	.90	.76	1.25	.4	.12	2.2	.70	1.2	.37	.88	.90	1.00
			290	5.7	3.6	2.1	1.47	1.60	1.61	1.35	1.48	1.27	1.00	1.65	.4	.10	2.5	.69	1.2	.33	.89	.92	1.00
			330	4.5	2.5	2.0	1.35	1.50	1.45	1.25	1.35	1.35	.90	1.50	.1	.03	1.7	.70	1.0	.40	.90	.90	1.00
			370	3.9	1.8	2.1	1.14	1.25	1.30	.96	1.13	1.15	.72	1.32	.0	.00	1.2	.68	.5	.28	.86	.91	1.01
			410	4.2	2.1	2.1	.98	1.12	1.16	.81	.98	.92	.34	1.20	.1	.04	1.4	.68	.6	.29	.82	.87	.99
			450	3.8	1.8	2.0	.82	.91	.86	.80	.83	.65	.65	.92	.3	.16	1.3	.72	.7	.39	.90	.91	.99
Mean of 10 curves				5.0	3.0	2.04	1.32									.10		.71		.37	.87	.89	1.00

Vertical velocity measurements—Continued.

MAUMEE RIVER AT SHERWOOD, OHIO.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 11[b]	3.34	2.79	50	.....	2.6	0.7	0.69	0.76	0.73	0.65	0.69	0.61	0.51	0.76	0.3	0.11	1.8	0.71	1.0	0.38	0.86	0.91	1.00
			70	.....	2.3	.6	.69	.74	.72	.64	.68	.63	.50	.75	.2	.11	1.6	.70	.9	.39	.92	.93	1.01
			90	.....	2.6	.5	.68	.71	.71	.68	.70	.68	.56	.72	.4	.13	1.7	.65	.9	.35	.95	.96	.98
			110	.....	2.5	.5	.82	.90	.88	.75	.82	.76	.48	.91	.2	.08	1.8	.69	.9	.36	.90	.91	1.00
			130	.....	2.4	.6	.81	.83	.89	.72	.80	.90	.62	.90	.....	.....	1.4	.58	.2	.08	.90	.98	1.00
			160	.....	2.3	.5	.93	.98	.93	.92	.92	.83	.72	.98	.5	.22	1.8	.78	1.2	.52	.95	.95	1.00
			180	.....	2.7	.6	.87	.91	.98	.73	.86	.97	.57	.99	.....	.....	1.6	.59	.4	.15	.88	.96	1.02
			200	.....	2.6	.6	.78	.82	.86	.69	.78	.82	.58	.86	.....	.....	1.6	.62	.6	.23	.91	.95	1.00
			220	.....	2.7	.6	.84	.90	.92	.73	.82	.78	.54	.93	.2	.05	1.8	.67	.9	.33	.90	.93	1.02
			240	.....	2.3	.7	.70	.72	.68	.68	.68	.58	.62	.72	.7	.31	1.8	.78	1.1	.48	.97	.97	1.03
			260	.....	2.4	.5	.82	.85	.83	.81	.82	.73	.75	.85	.4	.18	1.8	.75	1.1	.46	.97	.96	1.00
Mean of 11 curves	.....	.....	.....	.....	2.5	.58	.78	.....	.....	.....	.....	.....	.....	.....	.....	.11	.....	.68	.....	.34	.92	.95	1.01

MOHAWK RIVER AT SCHUYLER STREET BRIDGE, UTICA, N. Y.[c]

1902.																							
December 10	16.4	.....	20	11.0	10.5	0.50	0.74	0.91	0.60	0.80	0.70	0.55	0.50	0.95	3.9	0.37	9.0	0.86	6.0	0.57	0.78	0.81	1.06
			30	11.6	11.1	.50	.90	1.08	.68	1.00	.84	.56	.73	1.10	4.0	.36	10.4	.93	6.5	.59	.82	.83	1.07
			40	11.4	10.9	.50	.88	1.10	.62	1.02	.82	.52	.68	1.15	3.8	.36	9.8	.90	7.0	.64	.76	.80	1.07
			50	11.0	10.5	.50	1.03	1.22	.88	1.10	.99	.74	.83	1.23	3.0	.28	8.9	.85	5.6	.53	.84	.84	1.04
			60	9.6	9.1	.50	.97	1.20	.90	1.00	.95	.10	.71	1.20	2.0	.22	7.6	.84	4.5	.49	.81	.81	1.02
Mean of 5 curves	.....	.....	.....	10.9	10.4	.50	.90	.....	.....	.....	.....	.....	.....	.....	.....	.32	.....	.88	.....	.56	.80	.82	1.05
December 11	16.0	.....	10	9.2	8.7	.50	.45	.58	.52	.38	.45	.35	.28	.60	.8	.09	6.2	.71	3.0	.34	.75	.78	1.00
			20	11.0	10.5	.50	1.00	1.20	1.20	.75	.98	.62	.38	1.28	1.0	.10	8.4	.80	5.5	.50	.98	1.00	1.02
			30	11.8	11.3	1.15	.50	1.38	1.10	1.10	1.10	1.05	.97	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1902.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 11	16.0		40	11.4	10.9	0.50	1.20	1.40	1.30	1.04	1.17	0.56	0.65	1.45	2.1	0.19	7.6	0.70	4.3	0.40	0.83	0.86	1.03
			50	10.9	10.4	.50	1.40	1.48	1.42	1.10	1.26	1.05	.70	1.55	2.0	.20	8.3	.80	4.0	.38	.90	.95	1.11
			60	10.1	9.6	.50	1.28	1.40	1.26	1.12	1.19	1.10	.75	1.40	2.2	.23	6.7	.70	5.0	.52	.91	.91	1.08
			70	9.8	9.3	.50	1.05	1.32	1.12	1.00	1.06	.48	.50	1.32	1.5	.16	7.2	.78	4.5	.48	.80	.80	.99
			80	9.3	8.8	.50	.92	1.10	1.00	.75	.88	.65	.20	1.10	1.9	.22	6.0	.68	3.5	.40	.84	.84	1.05
Mean of 5 curves				10.4	9.9	.50	1.06									.18		.72		.42	.83	.85	1.04

OLENTANGY RIVER AT COLUMBUS, OHIO.[a]

1906.																							
February 13	6.77	6.22	20	2.5	2.0	0.5	0.16	0.19	0.22	0.10	0.16	0.17	0.00	0.22			1.2	0.62	0.6	0.30	0.73	0.84	1.00
			30	4.3	3.8	.5	.34	.38	.38	.30	.34	.32	.20	.39	0.2	0.05	2.5	.65	1.3	.34	.87	.90	1.00
			40	5.0	4.5	.5	.29	.30	.29	.28	.28	.27	.27	.30	.7	.16	2.8	.62	1.8	.40	.97	.97	1.02
			60	4.6	4.0	.6	.22	.24	.26	.17	.22	.23	.12	.27			2.5	.62	1.0	.25	.82	.92	1.02
			80	4.4	3.8	.6	.15	.18	.17	.14	.16	.10	.10	.18	.5	.13	2.7	.71	1.6	.41	.83	.83	.97
Mean of 5 curves				4.2	3.6	.54	.23									.07		.64		.34	.84	.89	1.00

[a] Gravel and silt bed.

Vertical velocity measurements—Continued.

RAQUETTE RIVER AT MASSENA SPRINGS, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 28	10.31	.....	40	11.6	9.1	2.5	3.24	3.56	3.40	3.15	3.28	.....	2.20	3.58	1.0	0.11	6.9	0.76	4.0	0.44	0.99	0.91	0.99
			60	11.9	10.1	1.8	3.34	3.72	3.80	2.85	3.32	.....	1.73	3.86	.0	.....	6.8	.67	3.3	.33	.96	.90	1.01
			80	11.1	9.4	1.7	3.28	3.74	3.42	3.25	3.33	.....	2.24	3.78	1.5	.16	7.4	.79	3.8	.40	.99	.88	.99
			100	12.3	10.4	1.9	3.04	3.59	3.40	2.62	3.01	.....	1.51	3.61	.7	.07	7.3	.70	4.5	.43	.99	.85	1.01
			120	12.1	10.2	1.9	3.26	3.60	3.50	3.00	3.25	.....	2.02	3.64	1.0	.10	7.3	.72	3.6	.36	.99	.90	1.00
			140	13.8	12.0	1.75	3.34	3.76	3.38	3.28	3.33	.....	2.15	3.76	2.4	.20	6.3	.52	5.8	.48	1.00	.89	1.00
Mean of 6 curves	.....	.....	.....	12.1	10.2	1.92	3.25	.....	.....	.....	.....	.....	.....	.....	.....	.11	.....	.69	.....	.41	.99	.89	1.00
March 29	8.77	.....	40	10.0	8.0	2.0	2.84	3.34	3.00	2.58	2.79	.....	1.76	3.36	1.2	.15	5.8	.72	3.5	.44	.85	.85	1.02
			60	10.4	8.9	1.5	3.04	3.43	3.25	2.92	3.08	.....	2.22	3.50	1.4	.15	6.6	.75	3.3	.37	.87	.89	.99
			80	9.9	8.4	1.5	2.87	3.35	2.95	2.82	2.88	.....	1.28	3.37	1.6	.16	6.6	.79	3.5	.42	.85	.86	1.00
			100	10.5	8.8	1.7	2.75	3.32	2.80	2.60	2.70	.....	1.52	3.36	1.6	.19	6.6	.75	3.8	.43	.82	.83	1.02
			120	10.6	9.1	1.5	3.30	3.66	3.45	3.15	3.30	.....	2.44	3.73	1.5	.17	6.7	.74	3.2	.35	.88	.90	1.00
			140	12.4	10.9	1.5	3.30	3.75	3.35	3.30	3.32	.....	2.00	3.75	2.0	.18	8.6	.79	5.2	.48	.88	.88	.99
Mean of 6 curves	.....	.....	.....	10.6	7.4	1.62	3.02	.....	.....	.....	.....	.....	.....	.....	.....	.17	.....	.76	.....	.42	.86	.87	1.00
March 30	9.73	.....	40	10.9	9.0	1.9	3.76	4.08	4.45	3.15	3.80	.....	2.44	4.48	.3	.29	5.6	.62	2.2	.24	.84	.92	.99
			60	11.3	10.3	1.0	3.51	3.74	3.55	3.40	3.48	.....	2.84	3.74	1.8	.17	7.6	.74	4.9	.48	.94	.94	1.01
			80	10.7	9.2	1.5	3.19	3.51	3.15	3.28	3.22	.....	2.59	3.51	2.0	.22	7.7	.84	5.0	.54	.89	.91	.99
			100	11.3	10.3	1.0	3.23	3.99	3.08	3.18	3.13	.....	1.96	3.99	2.4	.23	8.0	.78	5.2	.50	.81	.81	1.03
			120	11.6	10.6	1.0	3.58	4.24	3.32	3.70	3.51	.....	2.76	4.27	2.8	.26	8.8	.83	5.7	.54	.84	.84	1.02
Mean of 5 curves	.....	.....	.....	11.2	9.9	1.28	3.45	.....	.....	.....	.....	.....	.....	.....	.....	.23	.....	.76	.....	.46	.86	.88	1.01

[a] Coarse gravel bed.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.						
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 6 [b]	6.80	.....	50	5.6	5.4	0.2	0.47	0.62	0.45	0.48	0.46	0.08	0.21	0.62	1.1	0.20	4.4	0.82	2.8	0.52	0.76	0.76	1.02
1902.																							
January 14	7.00	.....	40	4.8	4.0	.8	.72	.78	.48	.79	.64	.07	.67	.96	1.4	.35	.....	.....	2.5	.62	.75	.92	1.12
			50	6.4	6.0	.4	.82	.90	.80	.83	.82	.65	.62	.90	1.4	.23	4.9	.82	3.0	.50	.91	.91	1.00
			60	6.4	6.0	.4	.94	1.17	.78	1.04	.91	.38	.65	1.18	1.8	.30	5.2	.87	3.5	.58	.80	.80	1.03
Mean of 4 curves	.....	.....	.....	5.8	5.3	.45	.74	.....	.....	.....	.....	.....	.....	.....	.....	.27	.....	.88	.....	.56	.80	.85	1.04
1906.																							
February 17 [c]	5.15	.....	50	6.7	4.9	.75	.32	.44	.46	.38	.42	.38	.00	.46	.....	.....	4.4	.91	1.5	.31	.70	.74	.76
			60	7.1	4.3	.80	.26	.48	.40	.35	.38	.26	.00	.46	.....	.....	3.8	.90	2.3	.54	.58	.55	.70
			70	7.5	5.5	.72	.37	.55	.52	.38	.45	.46	.00	.55	.....	.....	4.5	.82	2.4	.43	.68	.62	.82
Mean of 3 curves	.....	.....	.....	7.1	4.9	.76	.32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.87	.....	.42	.65	.63	.76
February 17	5.15	.....	80	7.7	7.1	.72	.51	.56	.60	.44	.52	.50	.26	.60	.....	.....	5.0	.70	1.9	.27	.85	.91	.98
			90	7.7	7.1	.78	.56	.65	.77	.30	.54	.66	.00	.78	.....	.....	4.4	.61	1.4	.20	.72	.86	1.04
			100	6.4	5.8	.75	.60	.65	.70	.50	.60	.56	.36	.70	.1	.02	3.8	.64	1.4	.25	.85	.92	1.00
Mean of 3 curves	.....	.....	.....	7.3	6.7	.75	.55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.65	.....	.24	.80	.89	1.00

[a] Rock bed.

[b] Ice cover very rough—broken and tilted.

[c] Needle ice on bed of stream.

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In percent of depth.	In feet.	In percent of depth.	In feet.	In percent of depth.			
1901.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
December 11	11.5	.....	53	9.9	9.2	0.70	2.45	2.75	2.45	2.51	2.48	1.85	1.80	2.76	2.4	0.26	7.5	0.82	5.0	0.54	0.89	0.89	0.99
			64	10.7	10.0	.70	2.17	2.65	2.98	1.22	2.10	2.24	.20	3.25	.....	.....	6.0	.60	2.4	.24	.67	.82	1.03
			75	12.2	11.5	.70	2.64	3.03	2.98	2.25	2.61	2.15	1.35	3.23	1.2	.10	7.9	.69	3.8	.33	.82	.87	1.01
			85	12.3	11.6	.70	2.60	2.98	2.96	2.25	2.60	2.25	1.20	3.13	.8	.07	8.1	.70	4.3	.37	.83	.87	1.01
Mean of 4 curves	.....	.....	.....	11.3	10.6	.70	2.46	.....	.....	.....	.....	.....	.....	.....	.....	.10	.....	.70	.....	.37	.80	.86	1.01
December 19[b]	13.7	.....	115	18.0	13.5	4.50	2.44	2.97	2.24	2.70	2.47	.55	1.04	3.00	3.5	.26	12.0	.89	7.5	.56	.81	.82	.99
			95	16.0	16.0	.05	3.48	4.00	3.22	3.74	3.48	2.35	2.25	4.14	4.4	.27	13.7	.86	9.5	.59	.84	.87	1.00
			85	15.6	15.6	.05	3.40	3.94	3.13	3.60	3.36	2.15	2.20	3.96	4.3	.28	13.4	.86	8.5	.54	.86	.86	1.01
			75	14.5	13.5	1.00	2.63	3.10	2.44	2.89	2.66	.85	2.30	3.13	3.5	.26	12.4	.92	7.6	.56	.84	85	.99
Mean of 4 curves	.....	.....	.....	16.0	14.6	1.40	2.98	.....	.....	.....	.....	.....	.....	.....	.....	.27	.....	.88	.....	.56	.84	85	1.00
1902.																							
January 21	7.24	.....	50	.....	3.4	<1.20	.81	.88	.90	.70	.80	.68	.10	.95	.4	.10	2.5	.74	1.2	.35	.85	.92	1.01
			70	.....	5.0	.....	1.01	1.10	1.14	.85	1.00	.96	.36	1.18	.1	.02	3.4	.68	1.8	.36	.85	.92	1.00
			80	.....	5.8	.....	1.01	1.17	1.07	.94	1.00	.66	.55	1.19	.9	.15	4.3	.74	2.1	.36	.84	.86	1.01
			90	.....	6.6	.....	1.02	1.20	1.22	.88	1.05	.45	.50	1.25	.8	.12	4.7	.71	2.2	.33	.82	.85	.97
			100	.....	7.8	.....	1.08	1.25	1.18	.96	1.07	.70	.50	1.27	.8	.10	5.7	.73	3.2	.41	.85	.87	1.00
			110	.....	8.4	.....	.39	.50	.43	33	.38	.22	.14	.52	1.4	.17	6.0	.72	3.4	.41	.75	.78	1.02
Mean of 6 curves	.....	.....	.....	.....	6.2	1.20	.89	.....	.....	.....	.....	.....	.....	.....	.....	.11	.....	.72	.....	.37	.83	.87	1.00
January 23[d]	17.33	.....	30	14.4	13.0	1.40	2.20	2.58	1.96	2.37	2.16	1.58	1.40	2.65	4.0	.31	10.8	.83	8.0	.62	.83	.85	1.02
			40	15.4	14.0	1.40	3.13	3.62	3.23	3.13	3.18	1.60	1.30	3.62	2.2	.16	11.2	.80	6.5	.47	.86	.87	.[illegible]
			50	18.0	17.0	1.00	3.63	4.00	3.70	3.72	3.71	1.45	1.60	4.00	3.1	.18	14.7	.87	7.5	.44	.91	.91	.[illegible]
			60	16.0	15.2	.80	4.10	4.24	4.21	4.02	4.12	2.70	2.90	4.28	2.2	.15	11.6	.76	.....	.....	.....	.....	1.[illegible]

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1902.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 23	17.33		90	22.2	21.5	0.70	3.93	4.27	4.23	3.63	3.93	2.80	2.00	4.37	1.5	0.07	15.0	0.70	8.0	0.37	0.90	0.92	1.00
			100	21.6	20.8	.80	3.89	4.20	3.90	4.00	3.95	2.00	2.20	4.20	4.0	.19	18.0	.87	10.0	.48	.93	.93	.98
			110	23.2	22.4	.80	3.73	4.17	3.82	3.80	3.81	2.20	2.00	4.18	3.8	.17	17.4	.78	9.5	.42	.89	.90	.98
			120	16.8	16.0	.80	2.77	3.22	3.20	2.50	2.85	1.60	1.10	3.45	2.0	.12	11.4	.71	5.2	.33	.80	.87	.97
Mean of 10 curves				19.1	18.2	.92	3.54									.16		.79		.43	.89	.91	.99
January 31	9.07		40	6.8	5.8	1.00	1.52	1.70	1.60	1.42	1.51	1.20	.92	1.73	.9	.15	4.3	.74	2.2	.38	.88	.90	1.00
			50	6.2	5.1	1.00	1.86	2.06	2.09	1.62	1.85	1.60	.96	2.13	.3	.06	3.4	.69	1.6	.31	.87	.90	1.00
			60	5.1	4.1	1.00	1.74	2.06	2.09	1.35	1.72	1.48	.46	2.15	.2	.05	2.9	.71	1.3	.32	.81	.84	1.01
			70	8.8	7.8	1.00	2.08	2.35	2.34	1.83	2.08	1.72	.95	2.43	.7	.09	5.3	.68	2.6	.33	.86	.89	1.00
			80	8.8	7.8	1.00	2.14	2.35	2.38	2.02	2.20	1.28	1.30	2.45	.9	.12	5.6	.72	2.4	.31	.87	.91	.98
			90	10.0	9.0	1.00	2.09	2.37	2.38	1.83	2.10	1.15	1.15	2.46	1.0	.11	6.2	.69	3.0	.33	.86	.88	1.00
			100	11.5	10.3	1.20	2.24	2.48	2.28	2.24	2.26	1.62	1.35	2.48	1.4	.14	7.9	.77	4.5	.44	.90	.90	.99
Mean of 7 curves				8.2	7.1	1.03	1.95									.10		.71		.34	.86	.89	1.00
February 10	7.8		80	7.5	6.5	1.00	1.43	1.61	1.54	1.32	1.43	.95	.88	1.68	1.0	.15	4.6	.71	2.5	.38	.85	.89	1.00
			90	8.5	7.5	1.00	1.43	1.58	1.66	1.22	1.44	.90	.90	1.74	.7	.09	4.8	.64	2.2	.29	.82	.91	.99
			100	9.6	8.6	1.00	1.53	1.80	1.56	1.43	1.50	1.12	.90	1.81	1.6	.19	6.3	.73	4.0	.46	.84	.84	1.02
			110	10.1	8.9	1.20	.78	.82	.50	.96	.73	.28	.61	.98	4.0	.45	8.4	.94	6.6	.74	.80	.95	1.07
Mean of 4 curves				8.9	7.9	1.05	1.29									.22		.76		.46	.82	.90	1.02
February 24	7.35		40	5.7	3.5	[a]2.20	.53	.63	.60	.45	.52	.25	.26	.64	.4	.11	2.4	.70	2.4	.69	.83	.84	1.02
			80	7.3	5.3	2.00	.84	.98	.92	.84	.72	.65	.45	1.02	1.1	.21	3.4	.64	2.0	.38	.82	.86	1.00
			90	8.0	6.0	2.00	.86	1.00	1.02	.72	.87	.60	.50	1.08	.4	.07	4.0	.67	2.0	.33	.80	.86	.99
			100	9.0	7.0	2.00	.98	1.12	1.05	.84	.94	.69	.50	1.13	.9	.13	5.0	.71	2.8	.40	.87	.87	1.04
			110	9.3	7.0	2.30	.53	.61	.58	.44	.51	.42	.24	.63	.6	.09	4.8	.69	2.6	.37	.84	.87	1.04
Mean of 5 curves				7.9	5.8	2.10	.75									.12		.68		.43	.83	.86	1.02

[a] Thickness of ice as given includes considerable water above ice.

Vertical velocity measurements—Continued.

WALLKILL RIVER AT NEWPALTZ, N. Y.—Continued.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8 \text{ depth.}}{2}$	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1903.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
January 7	11.2	.....	60	7.6	6.8	0.80	2.23	2.51	2.77	1.66	2.22	2.00	1.00	2.80	1.2	0.22	4.2	0.61	1.8	0.26	0.80	0.89	1.00
			80	11.1	10.3	.80	2.54	2.74	2.91	2.25	2.58	1.60	1.80	2.94	.6	.06	7.0	.68	2.9	.28	.86	.93	.99
			90	11.6	10.8	.80	2.38	2.57	2.68	2.20	2.44	1.30	1.70	2.72	1.0	.09	7.6	.70	3.1	.28	.87	.93	.98
			110	13.1	12.3	.80	2.52	2.82	2.63	2.58	2.60	1.74	1.70	2.83	1.8	.15	10.0	.81	5.2	.42	.89	.90	.97
Mean of 4 curves				10.8	10.0	.80	2.42									.13		.70		.31	.86	.91	.99
February 10	10.8	.....	25	.....	4.8	1.33	1.29	1.42	1.38	1.14	1.26	1.00	.82	1.42	.2	.04	3.2	.67	2.2	.46	.91	.91	1.02
			40	.....	8.0	1.00	2.26	2.44	2.20	2.30	2.25	1.86	1.95	2.43	2.0	.25	6.6	.82	4.0	.50	.93	.92	1.00
			60	.....	6.0	1.00	2.17	2.59	2.55	1.71	2.15	1.70	.90	2.65	.4	.07	4.1	.68	2.1	.35	.82	.84	1.01
			80	.....	9.6	1.00	2.53	2.78	2.79	2.32	2.56	1.80	1.50	2.89	.8	.08	6.6	.69	2.7	.29	.88	.91	.99
			110	.....	11.8	1.00	2.65	3.00	2.81	2.52	2.66	1.98	.80	3.02	1.4	.12	9.1	.77	5.2	.44	.88	.88	1.00
Mean of 5 curves					8.0	1.06	2.18									.11		.72		.41	.88	.89	1.00
February 26	8.85	.....	25	5.2	5.2	1.20	.59	.63	.72	.52	.62	.42	.15	.76	.3	.06	2.4	.46	2.3	.44	.78	.94	.95
			40	7.0	5.8	1.20	1.20	1.31	1.40	1.15	1.28	1.00	.00	1.43	.4	.06	4.2	.72	1.2	.21	.84	.92	.94
			60	5.2	4.2	1.00	1.12	1.40	1.42	.73	1.08	.90	.00	1.53	.3	.07	2.8	.67	1.4	.34	.73	.80	1.04
			80	8.8	7.8	1.00	1.43	1.58	1.58	1.30	1.44	1.15	.65	1.68	.6	.08	5.8	.74	2.8	.36	.85	.90	.99
			100	10.2	9.2	1.00	1.41	1.57	1.60	1.20	1.40	1.15	.62	1.68	.6	.07	6.4	.70	3.2	.35	.84	.90	1.00
			110	11.2	10.5	.70	1.87	2.04	1.80	1.92	1.86	1.30	1.27	2.20	2.7	.26	8.7	.83	6.2	.59	.85	.92	1.00
			120	8.5	7.9	.60	.68	.80	.70	.68	.69	.28	.20	.80	1.5	.19	6.3	.86	3.4	.43	.85	.85	.99
Mean of 7 curves				8.0	7.2	.96	1.20									.11		.70		.39	.82	.89	.99

...ontinued.

WEST CANADA CREEK AT TWIN ROCK BRIDGE, N. Y.[a]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8 \text{ depth.}}{2}$	Top.	Bottom.	Maximum.	Upper.		Lower.				Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
															In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.			
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
February 9[b]	3.03		25	3.6	2.4	1.25	1.58	1.78	1.71	1.48	1.60	1.00	0.98	1.81	0.3	0.14	1.8	0.74	1.0	0.41	0.87	0.89	0.99
			30	3.8	2.6	1.30	1.70	1.77	1.85	1.53	1.69	1.86	1.23	1.86	.....	.....	1.6	.62	.0	.....	.92	.96	1.00
			40	3.6	2.3	1.32	2.12	2.30	2.35	1.89	2.12	2.23	1.47	2.39	.....	.....	1.5	.65	.8	.32	.89	.92	1.00
			50	5.9	4.7	1.34	1.45	2.03	1.67	1.15	1.41	.86	.00	2.06	.6	.13	3.5	.75	2.0	.43	.70	.71	1.03
			60	6.5	5.0	1.48	.65	.72	.73	.54	.64	.50	.38	.76	.5	.10	3.0	.60	1.7	.34	.86	.90	1.02
February 10	3.03		120	5.0	3.4	1.58	1.10	1.13	1.16	1.02	1.09	1.16	.76	1.16	.....	.....	2.1	.62	.0	.....	.95	.97	1.01
			130	4.2	2.6	1.60	1.28	1.32	1.34	1.21	1.28	1.23	1.12	1.35	.2	.06	1.6	.62	.7	.27	.95	.97	1.00
			140	4.2	2.6	1.75	.95	1.03	.95	.93	.94	.80	.84	1.04	.5	.19	2.0	.77	1.0	.39	.91	.92	1.01
Mean of 8 curves				5.2	3.2	1.45	1.35	.....	.....	.....	.....	.....	.....	.....	.....	.08	.....	.67	.....	.27	.88	.91	1.01
1903.																							
February 21	3.8		20	3.8	2.3	1.5	1.65	1.84	1.70	1.56	1.63	1.53	.66	1.84	.3	.13	1.8	.78	1.4	.59	.90	.90	1.01
			25	4.1	2.6	1.5	1.57	1.70	1.79	1.26	1.52	1.61	.85	1.82	.....	.....	1.6	.62	.8	.31	.86	.92	1.03
			30	4.2	2.7	1.5	1.50	1.65	1.74	1.21	1.48	1.40	.84	1.76	.1	.04	1.5	.56	.8	.32	.85	.91	1.01
			35	4.2	2.7	1.5	1.65	1.84	1.80	1.51	1.66	1.46	.88	1.86	.1	.04	2.1	.76	1.0	.37	.90	.90	.99
			40	4.2	2.7	1.5	1.82	2.12	1.97	1.54	1.76	1.58	.92	2.18	.4	.13	1.9	.70	1.0	.39	.85	.86	1.03
			45	4.0	2.5	1.5	1.83	2.04	2.17	1.40	1.78	1.74	.90	2.24	.0	.02	1.5	.61	.8	.30	.82	.90	1.03
			50	3.9	2.2	1.75	2.18	2.30	2.30	1.97	2.14	2.00	1.69	2.34	.0	.02	1.5	.70	.8	.37	.93	.95	1.02
			55	3.8	2.0	1.75	2.22	2.31	2.38	1.99	2.18	2.32	1.54	2.38	.....	.....	1.3	.62	.5	.24	.93	.96	1.02
			60	4.0	2.5	1.5	2.00	2.19	2.45	1.56	2.00	2.30	.88	2.35	.....	.....	1.6	.63	.5	.20	.85	.91	1.00
Mean of 9 curves				4.0	2.5	1.56	1.82	.....	.....	.....	.....	.....	.....	.....	.....	.04	.....	.66	.....	.34	.86	.91	1.02

[a] Coarse gravel bed.

[b] Needle ice on under surface of ice.

Vertical velocity measurements—Continued.

WINOOSKI RIVER AT RICHMOND, VT.

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1905.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 3[a]	5.45	2.70	5	3.3	1.2	2.6	1.20	1.52	1.23	1.13	1.18	0.70	0.68	1.52	0.2	0.17	0.9	0.75	0.5	0.41	0.79	0.79	1.02
			10	4.0	1.9	2.5	1.78	2.02	2.09	1.50	1.80	1.20	.88	2.15	.2	.10	1.3	.69	.6	.32	.83	.88	.99
			15	3.9	1.8	2.4	2.09	2.34	2.27	1.92	2.10	1.72	1.02	2.36	.2	.06	1.3	.72	.7	.39	.89	.89	1.00
			20	3.6	1.9	2.25	2.29	2.74	2.54	2.00	2.27	1.55	.98	2.76	.2	.10	1.4	.74	.8	.42	.83	.84	1.01
			25	3.6	1.6	2.2	2.45	2.88	2.74	2.13	2.44	1.50	1.23	2.95	.1	.06	1.1	.69	.7	.44	.83	.85	1.01
			30	3.5	1.8	2.1	2.32	2.81	2.42	2.14	2.28	1.25	1.45	2.83	.3	.17	1.3	.72	.8	.44	.82	.83	1.02
			35	3.4	1.6	2.2	2.04	2.58	2.42	1.62	2.02	.90	.80	2.80	.2	.12	1.1	.69	.6	.38	.73	.79	1.01
			40	3.4	1.4	2.4	1.97	2.45	2.45	1.48	1.96	1.33	.25	2.53	.1	.07	1.0	.72	.5	.36	.78	.80	1.00
			45	3.4	1.6	2.1	2.05	2.50	2.32	1.70	2.01	1.13	1.09	2.65	.2	.12	1.0	.63	.5	.31	.77	.82	1.02
			50	3.3	2.0	1.5	1.70	2.55	2.35	.69	1.52	.62	.00	2.94	.2	.10	1.4	.70	.7	.35	.58	.67	1.12
			55	3.0	1.9	1.5	1.66	1.97	1.27	1.93	1.60	.83	1.20	2.22	.7	.37	1.7	.89	1.2	.63	.75	.84	1.04
			60	2.8	1.4	1.6	1.93	2.33	2.14	1.55	1.84	1.80	.78	2.33	.1	.07	1.0	.71	.7	.50	.83	.83	1.05
			65	2.2	.8	2.0	1.50	1.80	1.85	1.25	1.55	.56	.30	1.79	.1	.12	.6	.75	.2	.25	.84	.83	.97
Mean of 13 curves				3.3	1.6	2.10	1.92									.13		.72		.40	.79	.82	1.02
March 4[a]	5.58	2.83	5	3.4	1.3	2.75	1.41	1.67	1.46	1.25	1.36	1.25	.76	1.67	.2	.15	1.0	.77	.6	.46	.84	.84	1.04
			10	4.0	1.8	2.75	2.00	2.25	2.24	1.74	1.99	1.65	1.00	2.32	.1	.06	1.2	.67	.6	.33	.86	.89	1.01
			15	4.0	2.0	2.55	2.27	2.51	2.45	2.03	2.24	2.15	1.40	2.53	.1	.05	1.4	.70	.8	.40	.90	.90	1.01
			20	4.0	2.0	2.3	2.63	2.97	2.87	2.39	2.63	2.33	1.23	3.03	.2	.10	1.4	.70	.7	.35	.87	.88	1.00
			25	3.7	1.7	2.35	2.60	3.25	2.77	2.23	2.50	1.72	1.20	3.24	.3	.18	1.2	.71	.8	.47	.80	.80	1.04
			30	3.8	2.0	2.1	2.25	2.92	2.37	2.01	2.19	1.00	1.25	2.95	.4	.20	1.5	.75	.9	.45	.76	.77	1.02
			35	3.6	1.6	2.25	2.58	3.18	2.73	2.18	2.46	2.13	1.25	3.20	.2	.12	1.2	.75	.8	.50	.81	.81	1.05
			40	3.8	1.6	2.3	2.36	2.57	2.96	1.87	2.42	1.58	1.20	2.97	.1	.06	1.0	.63	.4	.25	.79	.92	.98
			45	3.6	1.7	2.1	2.54	3.23	2.67	2.23	2.45	1.50	1.30	3.27	.3	.18	1.2	.70	.8	.47	.78	.79	1.04
			50	3.5	2.1	1.55	2.50	3.23	2.50	2.30	2.40	.35	1.70	3.53	.4	.19	1.6	.76	.8	.38	.71	.77	1.04
			55	3.3	1.9	1.55	2.65	3.02	3.17	2.17	2.67	2.43	.75	3.18	.00	.00	1.3	.68	.6	.32	.83	.88	.99
			60	3.0	1.5	1.6	2.39	2.90	2.75	1.85	2.30	2.10	1.00	2.98	.00	.00	1.0	.67	.6	.40	.80	.82	1.04
			65	2.6	1.0	2.0	1.83	2.10	2.04	1.62	1.83	1.70	.65	2.13	.10	.10	.7	.70	.4	.40	.86	.87	1.00
Mean of 13 curves				3.6	1.7	2.17	2.31																

[illegible] one-half mile above bridge: Gravel [illegible]

Date.	Gage height to water surface.	Gage height to bottom of ice.	Distance from initial point.	Total depth.	Depth below ice.	Thickness of ice.	Velocity in feet per second from vertical velocity curves.								Depth of threads of mean velocity.				Depth of thread of maximum velocity.		Coefficients for reducing to mean velocity.		
															Upper.		Lower.						
							Mean.	0.5 depth.	0.2 depth.	0.8 depth.	$\frac{0.2+0.8}{2}$ depth.	Top.	Bottom.	Maximum.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	In feet.	In per cent of depth.	Maximum.	0.5 depth.	$\frac{0.2+0.8}{2}$ depth.
1906.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*																	
March 9[a]	5.62	3.42	21	11.5	9.0	2.5	1.74	2.19	1.13	2.27	1.70	0.50	1.28	2.46	3.3	0.37	8.5	0.94	5.8	0.64	0.71	0.80	1.02
			30	10.0	7.0	3.0	2.10	2.82	2.44	2.04	2.24	.20	.30	2.86	1.2	.16	5.6	.79	2.8	.40	.74	.74	.94
			40	7.5	4.8	2.75	2.24	2.69	2.38	1.96	2.17	2.02	.94	2.70	.6	.12	3.5	.74	2.4	.52	.83	.83	1.03
			50	7.3	5.3	2.0	2.02	2.86	2.03	1.77	1.90	1.46	.56	3.00	1.1	.21	4.1	.77	3.0	.57	.68	.71	1.07
			60	6.9	4.9	2.0	1.93	2.50	1.76	2.04	1.90	.50	1.00	2.52	1.1	.22	4.1	.84	2.2	.45	.77	.77	1.02
			60	7.0	5.0	2.0	1.80	2.50	1.41	2.15	1.78	.40	.70	2.52	1.5	.30	4.2	.83	2.7	.54	.72	.72	1.01
Mean of 6 curves				8.6	6.2	2.45	1.99									.22		.81		.52	.74	.76	1.02

[a] At bridge; sand and gravel bed; ice cover very rough, broken, and tilted.

SUMMARIES OF VERTICAL VELOCITY CURVES.

The mean results from the vertical velocity curves (pp. 47-7 have been arranged in three groups—(1) 352 curves for smooth i cover, (2) 51 curves for rough ice cover, (3) 13 curves for very rou ice cover. It will be noted that in some cases where gage heigh were approximately the same for different sets of curves they ha been combined. There is little difference between the results groups 1 and 2, but as rough ice cover was reported for group 2, seemed best not to include it in the larger list.

Summary of vertical velocity curves under ice cover.

SMOOTH ICE COVER.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Depth of threads of velocity.			Coefficient to reduce to mean velocity.			Bed of stream.
							Upper mean.	Lower mean.	Maximum.	Maximum.	0.5 depth.	$\frac{0.2+0.8 \text{ depth}}{2}$	
			Feet.	*Feet.*	*Feet.*	*Ft. per sec.*							
Catskill	South Cairo, N. Y.	4	2.82	2.7	0.98	0.44	0.06	0.70	0.31	0.80	0.85	0.98	Gravel.
Chemung	Chemung, N. Y.	4	2.85	3.7	.51	.64	.16	.79	.46	.86	.85	1.02	Coarse gravel.
Connecticut	Orford, N. H.	18	4.16	4.0	1.97	1.04	.11	.69	.37	.85	.88	1.00	Gravel and sand.
		12	± 4.1	4.1	1.91	.92	.07	.63	.25	.83	.92	.99	
		6	5.6	7.3	.....	1.80	.12	.73	.37	.87	.89	.99	
Esopus	Kingston, N. Y.	2	5.28	5.8	.10	.94	.16	.74	.52	.87	.87	1.02	Sand and gravel.
		8	5.60	3.4	.56	.80	.03	.63	.24	.76	.85	1.01	
		12	6.6	4.9	.10	1.19	.07	.69	.29	.82	.88	.98	
		8	7.0	5.0	.50	1.26	.08	.67	.36	.82	.86	.98	
Fish	Wallagrass, Me.	8	3.91	2.5	1.40	.90	.07	.70	.36	.88	.89	1.00	Gravel.
		8	5.00	3.5	1.45	1.25	.14	.77	.43	.84	.86	.98	
Genesee	Mount Morris (Jones Bridge), N.Y.	20	5.9	3.8	.54	1.62	.07	.67	.34	.80	.85	1.01	Coarse gravel.
Genesee	Rochester, N. Y.	11	1.42	6.6	.45	.45	.09	.72	.44	.84	.86	.99	Do.
		19	1.55	3.8	.43	.89	[a].01	.70	.33	.82	.87	1.00	
Kennebec	North Anson, Me.	4	3.40	2.7	.....	2.27	.....	.63	.19	.82	.92	1.00	Gravel.
		12	3.48	2.6	1.30	1.17	.04	.66	.30	.87	.91	.02	
		15	3.55	1.6	2.15	1.87	.18	.77	.45	.81	.82	1.01	
		19	4.17	2.5	1.91	1.30	.07	.69	.34	.86	.90	1.00	
		10	4.70	3.0	2.04	1.32	.10	.71	.37	.87	.89	1.00	
		9	4.77	2.9	2.34	1.33	.08	.70	.32	.87	.90	.98	
		23	5.30	3.2	2.00	1.61	.12	.70	.42	.83	.86	1.01	
Mohawk	Utica, N. Y.	13	[b] 16.2	10.1	.50	1.00	.21	.78	.47	.82	.84	1.04	Earth, very smooth.
Raquette	Massena Springs, N. Y.	17	9.6	9.2	1.60	3.24	.17	.74	.43	.90	.88	1.00	Coarse gravel.
Rondout Creek	Rosendale, N. Y.	3	5.15	6.7	.75	.55	[c]	.65	.24	.80	.89	1.00	Rock.
Wallkill	Newpaltz, N. Y.	11	7.3	6.0	±1.2	.83	.11	.70	.40	.83	.87	1.01	Clay and coarse gravel.
		4	7.78	7.9	1.05	1.29	.22	.76	.46	.82	.90	1.02	
		14	8.95	7.2	1.00	1.57	.10	.70	.36	.84	.89	1.00	
		13	11.2	9.5	.85	2.35	.11	.71	.36	.85	.89	1.00	
		10	17.33	18.2	.92	3.54	.16	.79	.43	.89	.91	.99	

[a] Upper thread of mean velocity at 4 curves only.

[b] Below reference point.

[c] Upper thread of mean velocity for 1 curve only.

Summary of vertical velocity curves under ice cover—Continued.

SMOOTH ICE COVER—Continued.

River.	Station.	Number of curves.	Gage height to water surface.	Depth under ice.	Ice thickness.	Mean velocity.	Depth of threads of velocity.			Coefficient to reduce to mean velocity.			Bed of stream.
							Upper mean.	Lower mean.	Maximum.	Maximum.	0.5 depth.	$\frac{0.2+0.8 \text{ depth}}{2}$	
			Feet.	*Feet.*	*Feet.*	*Ft. per sec.*							
West Canada Creek	Twin Rock Bridge, N. Y.	9	3.8	2.5	1.50	1.82	0.04	0.66	0.34	0.86	0.91	1.02	Coarse gravel.
Winooski	Richmond, Vt.	26	5.5	1.6	2.10	2.12	.12	.72	.40	.80	.83	1.02	Gravel.
Mean of 352 curves							.10	.71	.37	.839	.878	1.002	
Highest							.22	.79	.52	.90	.92	1.04	
Lowest							.00	.63	.19	.76	.82	.98	

ROUGH ICE COVER.

Connecticut	Orford, N. H.	7	5.59	4.6	1.71	1.08	0.08	0.70	0.37	0.86	0.88	1.00	Gravel and sand.
		7	6.00	4.9	1.69	1.11	.09	.70	.39	.84	.88	1.00	
		21	6.70	5.8	1.66	1.23	.14	.74	.42	.86	.88	1.00	
Des Moines	Keosauqua, Iowa	5	2.45	4.8	.46	1.58	.13	.73	.40	.86	.88	1.00	Gravel.
Maumee	Sherwood, Ohio	11	3.34	2.5	.58	.78	.11	.68	.34	.92	.95	1.01	Do.
Mean of 51 curves							.11	.71	.38	.868	.894	1.002	
Highest							.14	.74	.42	.92	.95	1.01	
Lowest							.08	.68	.34	.84	.88	1.00	

VERY ROUGH ICE COVER, BROKEN AND TILTED.

Rondout Creek	Rosendale, N. Y.	4	± 7.0	5.3	0.45	0.74	0.27	+∞0.88	0.56	0.80	0.85	1.04	Rock.
Wallkill	Newpaltz, N. Y.	4	13.7	14.6	1.40	2.98	.27	.88	.56	.84	.85	1.00	Clay and coarse gravel.
Winooski	Richmond, Vt.	5	5.62	6.2	±2.5	1.99	.22	.81	.52	.74	.76	1.02	Sand and gravel.
Mean of 13 curves				8.7	1.45	1.90	.25	.86	.55	.79	.82	1.02	

FORM OF VERTICAL VELOCITY CURVE.

For an ideal cross section and length of river, the difference in velocity at different points in a vertical section is due to the difference in resistance to flow met with by the filaments of water at different depths. If no resistances of any kind existed, the vertical curve of velocity would be a straight line normal to the surface of the stream. If bed friction and the incidental losses due to it were the only resistances to flow, the vertical velocity curve would probably be curved in the lower part and straight in the upper part, the line being tangent to the curve at that point in the vertical where the effect of bed resistance is lost (fig. 7, *a*); or if the bed friction is of sufficient amount relatively to the depth the curve might be continuous to the surface (fig. 7, *b*). Varying degrees between *a* and *b* would be met with, depending on the relation of depth to velocity, condition of bed, etc. If there is resistance at the surface due to air friction only, there would be a similar effect on the form of the curve

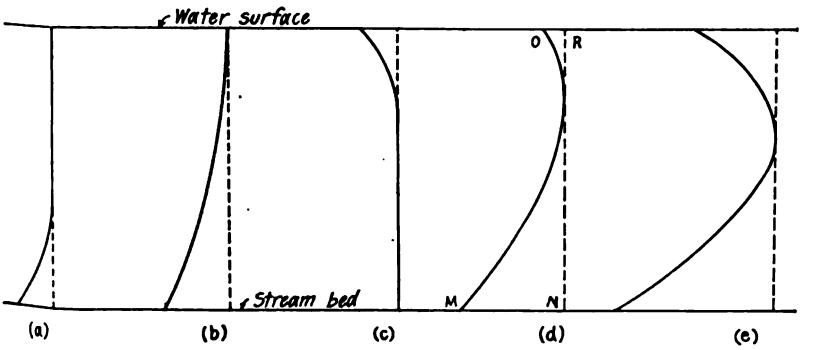


FIG. 7.—Form of vertical velocity curves.

from the surface downward. If there were no bed friction, the form of curve would be as in fig. 7, *c*, or some modification of this, as explained above.

Resistance to flow occasioned by the roughness of the sides of a stream is also an important factor in determining the form of the vertical velocity curve, especially if the channel is narrow and deep. F. P. Stearns[a] has advanced the theory that there is an upward flow toward the center at the surface. He says:

> Let us first suppose the case of a single obstacle projecting from the lining of a channel. The current approaching this obstacle loses some of its velocity just before reaching it, and thereby causes an excess of head in a small pyramid of water just above the projection.
>
> This excess of head in turn causes a transverse flow of the water in all directions; but the strongest transverse flow will be in the direction of the least resistance, which is, as a rule, vertically toward the surface.

[a] Trans. Am. Soc. Civil Eng., vol. 12, 1883, pp. 331 et seq.

The irregularities upon the surfaces of even the smoothest channel linings met within practice are very large in comparison with the size of the particles of water striking them, and they may be considered as obstacles present in all parts of the lining, each tending to produce an upward flow, as above indicated.

Although the tendency to upward flow is general, yet since it can not occur without a corresponding downward flow to replace the water which rises it follows that it will take place only in those portions of the width of the channel where the obstacles producing it are the more frequent and nearer the surface—i. e., generally at or near the sides.

It is therefore the theory that there is at the sides of channels an upward flow, due to the cause already described, which carries with it the slow-moving water always found in the immediate vicinity of channel linings, and that this water, reaching the surface, flows toward the middle of the channel, retarding by its slower movement the velocity of the surface layers, thereby causing the maximum velocity to be, in most cases, below the surface.

It must not be inferred from what has just been stated that the writer believes there is a continuous flow in the direction indicated, since it is well known that the motions of water are very irregular, particularly in channels with rough linings or variable sections, and that masses of water find their way from the bottom to the surface in the middle of the channel as well as elsewhere. The idea which he wishes to convey is that in most cases the resultants of these irregular movements are in the directions indicated.

The typical vertical velocity curve for open-water conditions (fig. 7, *d*) may be considered as due to a combination of these various resistances, but the amount and direction of the wind may change greatly the retardation due to air friction, and consequently the form of the curve. The relative effect of bed and surface friction will be in a measure shown by the difference in length of *mn* and *or*, or, in other words, the relation of surface and bottom velocities to the maximum velocity. If there is an ice cover the upper part of the vertical velocity curve will be still more curved (fig. 7, *e*), and, as shown later (pp. 78–79), may even be more pronounced in this way than the lower part.

The foregoing statements would apply to a straight stretch of river with the bed approximately parallel to the water surface. The usual uneven conditions of bed and banks have a modifying influence and tend to obscure more or less the relative effect of bed and surface friction. This relation of top and bottom velocity to the maximum will, however, serve to indicate something of the relative amount of resistance due to ice cover and to the stream bed, and will be briefly considered.

For open-water conditions the results from 78 vertical velocity curves under various conditions at gaging stations on New York streams are as follows:[a]

Relation of top, maximum, and bottom velocity for open-water conditions.

	Velocity in terms of mean velocity = 1.00	Difference as regards maximum velocity.
Top	1.15	0.0
Maximum	1.18	
Bottom	.50	.6

[a] See Water-Sup. and Irr. Paper No. 76, U. S. Geol. Survey, 1903, p. 25, fig. 3.

The relation of air or water surface friction to that of bed friction s here $\frac{2}{9}:\frac{2}{8}$, or 0.044. (Compare with Francis's ratio of $\frac{1}{810}$ for still air, p. 16.)

For smooth ice cover, the comparative effect of bed and ice friction is shown for several cases in the following table. The average amount of resistance due to ice cover is 0.58 of that due to roughness of bed, but there is considerable variation from this amount.

Comparative effect of bed and ice friction on vertical velocity curves under smooth ice cover.

River and station.	Gage height.	Number of curves	Average depth.	Average velocity.	Difference as regards maximum velocity.		Ratio of 1 to 2.
					Top (1).	Bottom (2).	
	Feet.		*Feet.*	*Feet per second.*			
Kenneber, North Anson, Me...	3.48	18	2.6	1.17	0.22	0.62	0.35
	4.17	19	2.5	1.30	.30	.62	.48
	4.77	9	2.9	1.33	.40	.57	.70
Connecticut, Orford, N. H.....	4.15	18	4.0	1.04	.50	.66	.76
	5.59	7	4.6	1.08	.27	.72	.38
	6.00	7	4.9	1.11	.32	.72	.44
	6.70	21	5.8	1.23	.41	.65	.63
Fish, Wallagrass, Me.....	3.91	8	2.5	.90	.23	.51	.45
	5.04	8	3.6	1.25	.64	.74	.86
Winooski, Richmond, Vt.....	.....	26	1.6	2.12	.59	.77	.77
Wallkill, Newpaltz, N. Y.....	.....	5	8.0	2.18	.37	.65	.57
Mean.....	.....	.....	.....	.....	.39	.66	.58

For very rough ice cover, the frictional effect of ice cover is the greater of the two, averaging 1.28 times that for roughness of bed.

Comparative effect of bed and ice friction on vertical velocity curves under very rough ice cover.

River and station.	Number of curves.	Average depth.	Average velocity.	Difference as regards maximum velocity.		Ratio of 1 to 2.
				Top (1).	Bottom (2).	
		Feet.	*Feet per second.*			
Rondout Creek, Rosendale, N. Y.....	4	5.3	0.74	1.02	0.55	1.86
Wallkill, Newpaltz, N. Y.....	4	14.6	2.98	.81	.89	.91
Winooski, Richmond, Vt.....	5	6.2	1.99	1.11	1.05	1.06
Mean.....	.....	.....	.....	.98	.83	1.28

RELATION OF DEPTH AND VELOCITY TO FORM OF CURVE.

It is evident from the foregoing tables that for a given mean velocity the vertical velocity curve under ice cover becomes flatter as the depth increases, since the curvature due to top and bottom resistances s distributed through a greater distance. (See fig. 13, p. 83.) For a given depth, as the mean velocity increases, the curvature will become greater, as both top and bottom resistances increase with velocity.

For a given station the change in curvature as the stage in will depend on the relative increase of depth and velocity. case of Wallkill River (fig. 10) the depth increases consid faster than the velocity, and it will be noted that the curve b flatter as the stage increases.

COMPARISON OF VERTICAL VELOCITY CURVES, WITH AND WI ICE COVER.

Fig. 8 affords a comparison of mean vertical velocity cur conditions of open water and ice cover, at substantially th stations. The essential difference between these curves is the

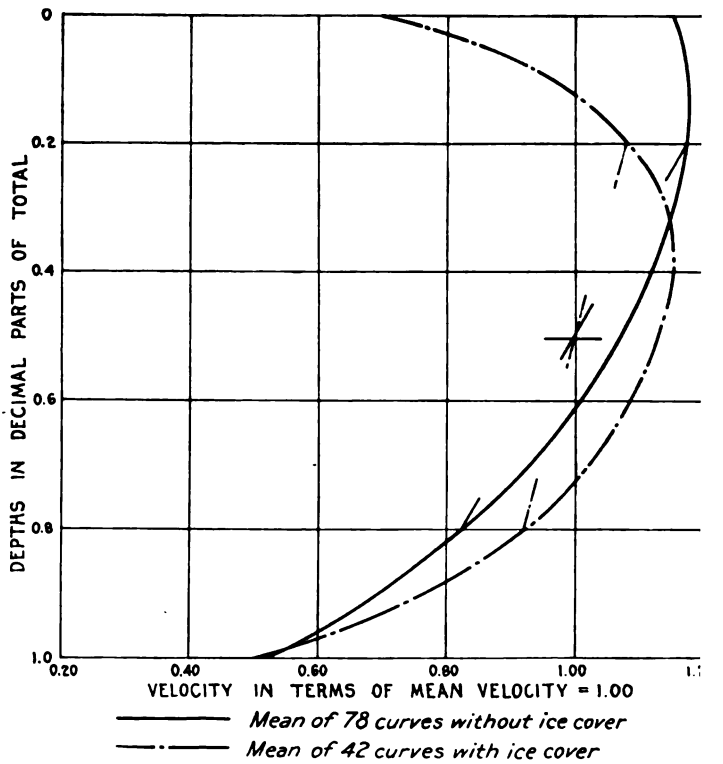


FIG. 8.—Comparison of vertical velocity curves for streams with and without ice cov

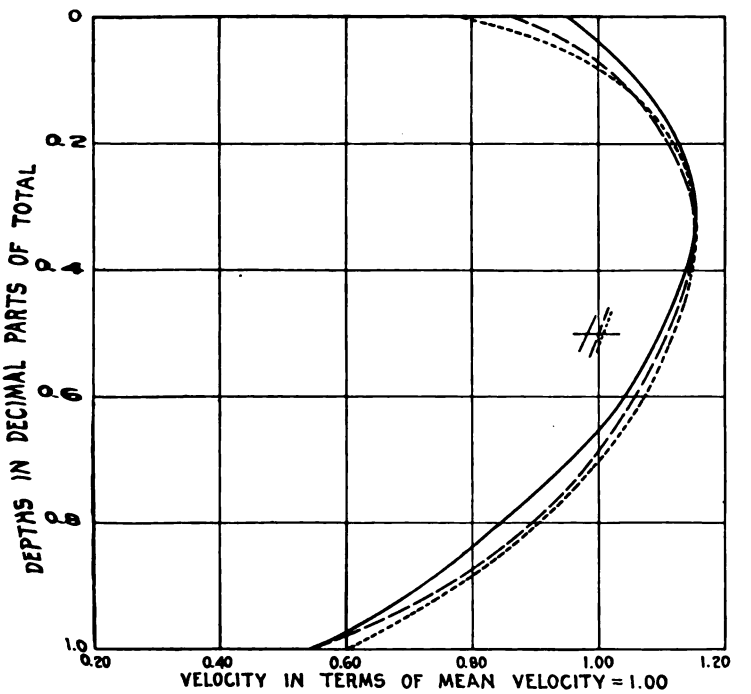
drawing back of the curve for ice cover in its upper portion, on a of the greater retarding effect of the ice over that of air. As a quence of this there are two threads of mean velocity, viz, at 0. 0.71 of the depth, for ice cover, as compared to one mean thr 0.61 depth for the open section. The position of maximum v is lowered from about 0.14 depth in the case of open section depth with ice cover, its relative value as regards mean velocity

slightly less in the case of ice cover. The bottoms of the two curves are at substantially the same position, as would be expected.

With very rough ice cover the difference between the two curves becomes still more pronounced, and the drawing back of the curve in its upper part may predominate over the curvature existing in the lower part due to roughness of bed.

POSITION OF THREADS OF MEAN VELOCITY.

The data in the table on pages 73–74 and figs. 8 to 14 serve as a basis for the following discussions, except where special reference is made to other material.

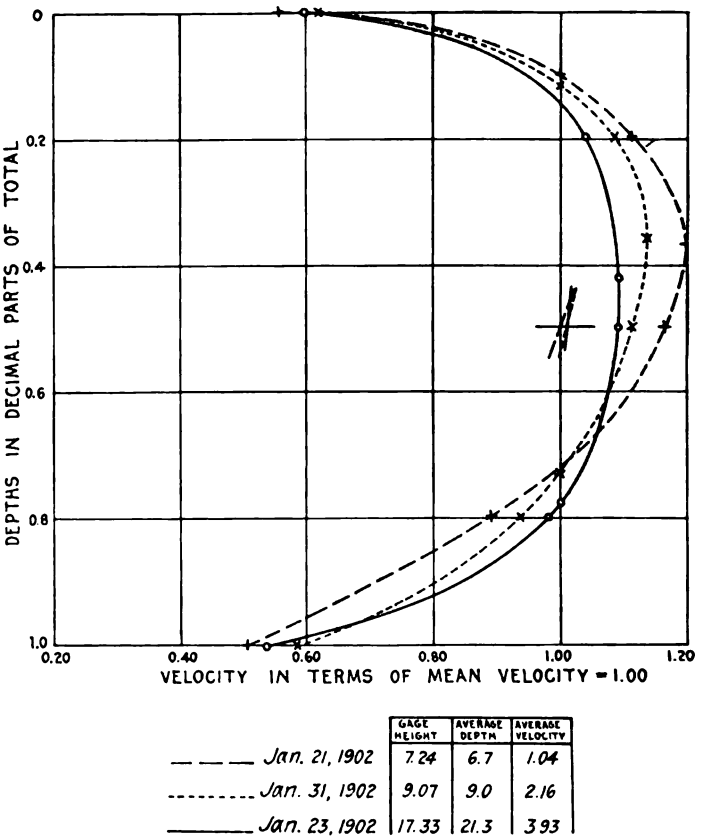


	GAGE HEIGHT	NO. OF CURVES	AVERAGE DEPTH	AVERAGE VELOCITY
———— Jan. 10, 1906	3.48	18	2.6	1.17
— — — — Mar. 2, 1906	4.17	19	2.5	1.30
---------- Mar. 30, 1906	4.77	9	2.9	1.33

FIG. 9.—Vertical velocity curves under ice cover, showing change in form of curve with change of stage, Kennebec River at North Anson, Me.

The average of 352 vertical velocity curves made under widely varying conditions (pp. 73–74) indicates that in general under ice cover two threads of mean velocity occur in the vertical, their average position being at 0.10 and 0.71 of the depth below the bottom of the ice.

The depths of threads of mean velocity being plotted as ordinates and the total depths as abscissas, it is seen that there is a general tendency for both threads to move toward the bottom of the curve as depth increases. A similar plat for depths of threads of mean velocity and for mean velocities indicates that as mean velocity increases both threads of mean velocity become lowered. An increase in stage for a given station means usually an increase of both depth and mean velocity; consequently it will be found



	GAGE HEIGHT	AVERAGE DEPTH	AVERAGE VELOCITY
— — — Jan. 21, 1902	7.24	6.7	1.04
..... Jan. 31, 1902	9.07	9.0	2.16
_____ Jan. 23, 1902	17.33	21.3	3.93

FIG. 10.—Vertical velocity curves under ice cover; average of curves at stations 80, 90, 100 for different stages, Wallkill River at Newpaltz, N. Y.

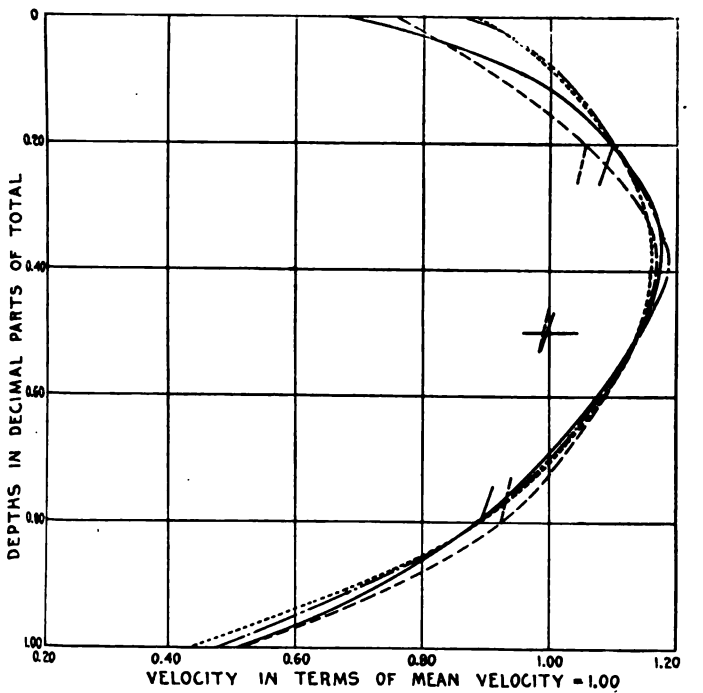
that both threads of mean velocity tend to move downward as the stage increases. (See figs. 9 to 11.)

The range in position of mean threads seems to be about the same for both upper and lower threads, being about 0.18 depth (with a few exceptions). Moreover, the change in position of the two threads is about the same in amount, the average difference being 0.60 of the depth. With very rough ice cover the tendency is toward greater depression of both mean threads, but it will be

ed that they still preserve about the same distance apart, viz, 0 depth. (See table on pp. 73–74, and fig. 14, p. 84).

SITION OF MAXIMUM VELOCITY AND RELATION TO MEAN VELOCITY.

The average position of maximum velocity is at 0.37 depth below ie ice, varying from 0.19 to 0.52 depth. In general, it becomes



	GAGE HEIGHT	NO. OF CURVES	AVERAGE DEPTH	AVERAGE VELOCITY
Feb. 1905	4.15	18	4.0	1.04
Feb. 1906	6.70	21	5.8	1.23
Mar. 1906	6.00	7	4.9	1.11
Mar. 1906	5.59	7	4.6	1.08

'G. 11.—Vertical velocity curves under ice cover, showing change in form of curve with change of stage, Connecticut River at Orford, N. H.

)wer as the depth and velocity increase and hence as the stage icreases. Rough ice cover tends also to lower the depth of the aximum thread, and when the ice becomes broken and tilted or hen needle ice accumulates near its under surface the thread may considerably below mid depth, indicating a greater effect due to friction than to that of the stream bed; in other words, the rve is a complete reversal of the ordinary open-water vertical locity curve.

The average coefficient to apply for obtaining maximum fr mean velocity is 0.839, the variation being from 0.76 to 0.90. T coefficient becomes less as the velocity increases, but greater as depth increases, consequently its variation from the mean is large for smooth ice. For rough ice it is considerably diminis and may reach a value of 0.75.

RELATION OF VELOCITY AT MID DEPTH TO MEAN VELOCITY.

The average coefficient for obtaining mean velocity from tha mid depth is 0.878, the range being from 0.82 to 0.92. The ra

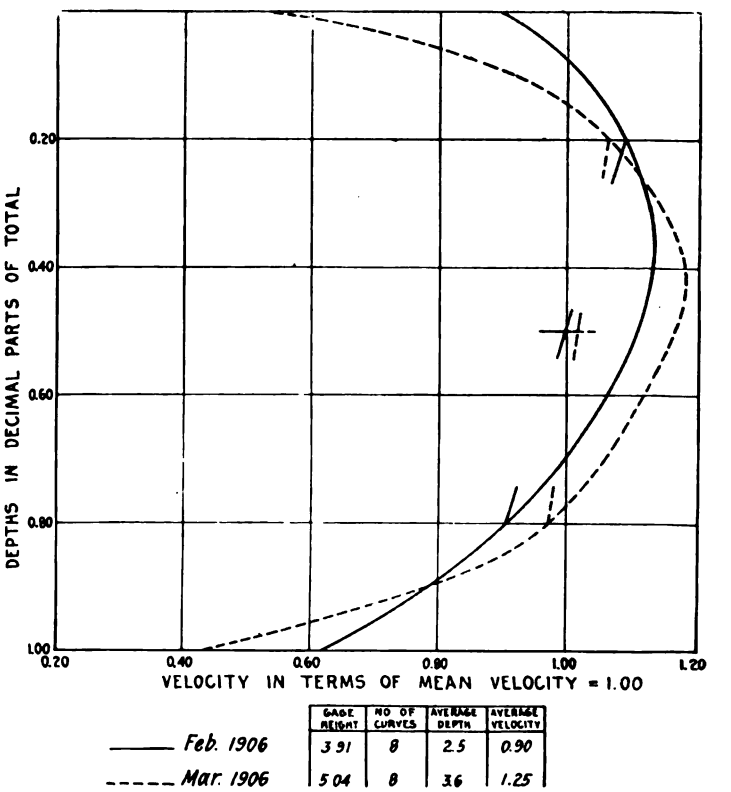


FIG. 12.—Vertical velocity curves under ice cover, Fish River at Wallagrass, Me.

in values for this coefficient, like that for maximum velocity, small, as the tendency is for it to increase directly with the de and inversely with the velocity; consequently for a given stat little variation occurs as the stage changes. Nearly this same av age relation was found on the upper Mississippi by A. O. Pow assistant engineer, under the direction of Col. Charles J. Allen, Co of Engineers, U. S. Army, in 1882 and 1890,[a] the variation be

[a] Ann. Rept. Chief of Engineers, U. S. A., 1890, pt. 3, p. 2104.

between 0.87+ and 0.88+. No data are given, however, as to conditions of depth, velocity, or bed of stream. The coefficient for obtaining mean velocity from that at mid depth becomes less for very rough ice, just as in the case for maximum velocity, the average value for the 13 curves being 0.82, with a range of from 0.76 to 0.85.

RELATION OF MEAN OF VELOCITIES AT 0.2 AND 0.8 DEPTH TO MEAN VELOCITY.

The average coefficient for obtaining mean velocity from the mean of the velocities at 0.2 and 0.8 depth is 1.002, the range being from

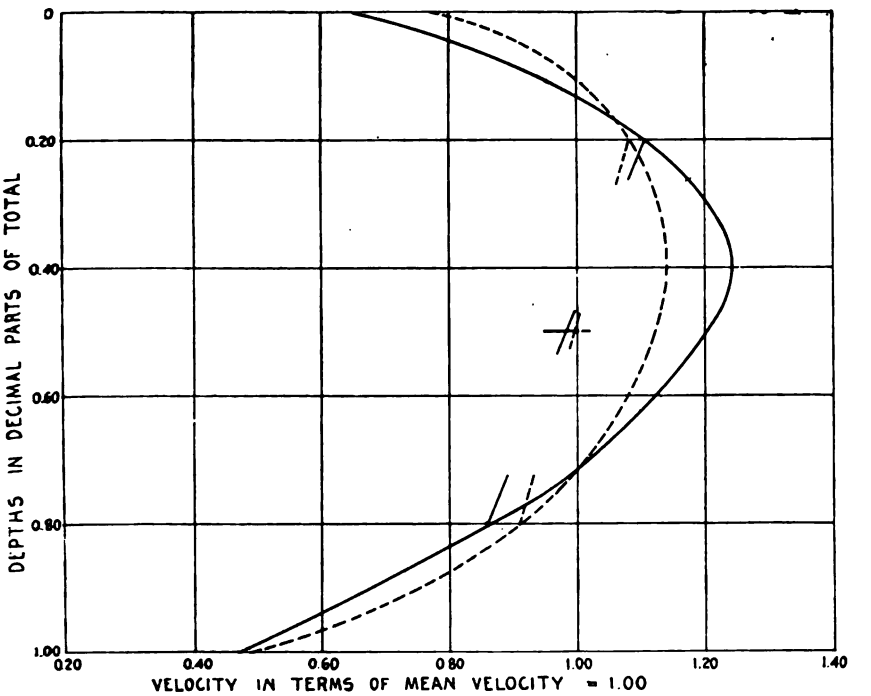


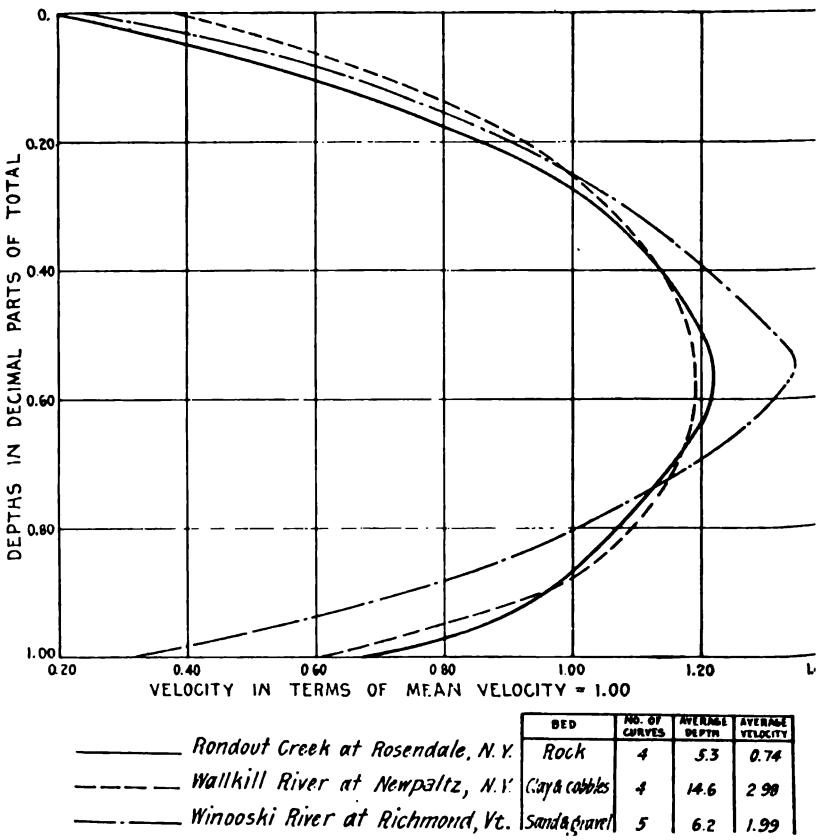
FIG. 13.—Effect of depth on form of vertical velocity curves under ice cover.

0.98 to 1.04, there being, however, but one set of curves with a greater value than 1.02. This relation is shown graphically by connecting the 0.2 and 0.8 depth points of the mean vertical velocity curves and noting where this line crosses the horizontal at 0.5 depth. (See figs. 8 to 13.)

In general, this coefficient seems to decrease slightly as gage heights increase. (See figs. 8 to 11, and table on pp. 73–74.) For very rough ice cover the mean value is 1.002, the range being from 1.00

to 1.04, indicating that rough ice tends to increase this coefficient slightly.

The typical vertical velocity curve for open-water conditions corresponds approximately in form with an ordinary parabola drawn through top, bottom, and mid-depth points of the curve and with axis horizontal. The mean ordinate to this parabola is a mean of the ordinates at 0.22 and 0.79 of the depth, and it is evident that the mean of the ordinates at 0.2 and 0.8 depth would always be less than the true mean ordinate, so that if the vertical velocity



	BED	NO. OF CURVES	AVERAGE DEPTH	AVERAGE VELOCITY
Rondout Creek at Rosendale, N.Y.	Rock	4	5.3	0.74
Wallkill River at Newpaltz, N.Y.	Clay & cobbles	4	14.6	2.98
Winooski River at Richmond, Vt.	Sand & gravel	5	6.2	1.99

FIG. 14.—Effect of very rough, broken, and tilted ice on form of vertical velocity curves under ice cov

curve were truly parabolic the coefficient for this method would always be slightly greater than 1.00. Usually the parabola passes wholly to one side of the actual curve above mid depth and on the opposite side below mid depth, the resulting effect being that the mean of the velocities at 0.2 and 0.8 depth ordinarily gives close the mean velocity for the vertical.

For ice cover the vertical velocity curve diverges markedly from a parabola drawn as described above. The results of the table on pages 73–74 seem to indicate, however, that this relation holds almost

as well for curves under ice cover as with open section, and the 0.2 and 0.8 method, as it is called, seems to have much promise as a two-point method, being both reasonably accurate and convenient for use.

The range of variation in the reduction of coefficients is as follows:

Range of coefficient to reduce to mean velocity.

Maximum	0.14
Mid depth	.10
0.2 and 0.8 depth	.06

The accuracy of the method being assumed to be proportional to the square root of the number of observations, and either of the single-point methods being adopted as a basis, the computed probable range of error for the two-point method would be

$$\frac{\text{Range for single point}}{\sqrt{2}},$$

or, as compared with maximum point, the range would be 0.099; with mid-depth point, the range would be 0.071. The actual range of variation for the two-point method is considerably smaller, indicating that it has a greater accuracy as compared with single-point methods than can be attributed to the use of two observations instead of one.

PERCENTAGE VARIATION IN OBSERVATIONS AT DIFFERENT DEPTHS.

In general the top and bottom of the vertical velocity curve is most poorly determined, because greater variations occur in velocity in these portions of the curve. The 0.5 depth method has the advantage of utilizing a depth of observation at which variations in velocity are least apt to occur.

As bearing on the variations between successive observations at 0.2 and 0.8 depth, the following table gives results from two sets of curves where independent observations were made at these depths just after the curves were completed:

Variation in observations at 0.2 and 0.8 depth, Connecticut River at Orford, N. H., meter suspended from cable.

MARCH 14, 1906, GAGE HEIGHT, 6.00.

	Observed velocity. Ratio: Velocity from curve.		Ratio of velocity determined by the 0.2 and 0.8 method to the mean velocity.		Depth under ice.	Mean velocity.
	0.2 depth.	0.8 depth.	Actual observation.[a]	From curve.[b]		
					Feet.	*Feet per second.*
Average of 7 curves	0.993	0.995	1.013	1.004	5.0	1.10
Highest	1.07	1.05	1.04	1.02	6.3	1.39
Lowest	.94	.95	.98	.99	3.5	.56

[a] Mean from 0.2 and 0.8 velocity as observed.
[b] Mean from 0.2 and 0.8 velocity taken from vertical velocity curve.

Variation in observations at 0.2 and 0.8 depth, Connecticut River at Orford, N. H., meter suspended from cable—Continued.

MARCH 15, 1906, GAGE HEIGHT 5.59.

	Observed velocity Ratio: Velocity from curve.		Ratio of velocity determined by the 0.2 and 0.8 method to the mean velocity.		Depth under ice.	Mean velocity.
	0.2 depth.	0.8 depth.	Actual observation.	From curve.		
					Feet.	*Feet per second.*
Average of 7 curves	1.006	0.974	1.011	1.003	4.6	1.08
Highest	1.04	1.13	1.05	1.01	5.7	1.38
Lowest	.95	.90	.97	.99	3.2	.51

As would be expected, the actual observations at 0.2 and 0.8 depth, when used to obtain mean velocity, give a larger percentage variation in coefficient than do the curve values at these depths, but the average variation is small and far within the degree of accuracy required.

A further index of the amount of variation in observations at 0.2 and 0.8 depth is afforded by two successive gagings made February 15, 1906, on Fish River at Wallagrass, Me., under ice cover, when the gage heights height remained the same.

Comparison of velocities for two separate gagings on Fish River at Wallagrass, Me., gage height 3.91, meter fastened to rod.

FEBRUARY 15, 1906, GAGE HEIGHT 3.91.

	Ratio of velocities obtained in first and second gagings.			Depth.	Mean velocity.
	0.2 depth.	0.8 depth.	Mean		
				Feet.	*Feet per second.*
Average of 4 stations, observations at 0.2 and 0.8 depth	1.002	0.972	0.990	2.6	0.88
Highest	1.06	1.08	1.05	4.1	1.10
Lowest	.93	.91	.94	.9	.62
Average of 4 stations, vertical velocity curves			0.978	2.5	.90
Highest			1.01	3.6	1.18
Lowest			.95	1.3	.86

Other details of these gagings are given on page 53. It will be noted that the depths are small and that in order to get 0.2 and 0.8 depth the meter had to be held within a range of 0.2 to 0.8 feet from the bottom of the ice and the bed of the river. The average variation in the results of these two sets of velocities at 0.2 and 0.8 depth is small and, in fact, is less than in the case of the vertical curves.

SLOPE DETERMINATIONS AND VALUES OF *n* IN KUTTER'S FORMULA, UNDER ICE CONDITIONS.

In 1906 two sets of slope determinations and measurements of the her hydraulic properties were made on Connecticut River at ford, N. H.

February 17, 1906.—River in general frozen. A strip of open ter, beginning at bridge, extended about 1,000 feet downstream. is was about 100 feet wide and approximately in the middle of the annel. The ice was rough in places and numerous ice cakes were zen in, owing to high water and a partial going out of the ice during nuary. There were about 11 inches of snow on the ice.

Bench marks, consisting in most cases of spikes in trees, were tablished along each bank by a double-rodded line of levels. undings for determination of cross section were made at 100 feet, 0 feet, and 516 feet upstream from the gage. The level was set on e ice in the middle of the river, and water-surface elevations were termined on both banks at each section at holes cut in the ice. The llowing table gives results of the best set of observations:

e determinations and value of "n" on Connecticut River at Orford, N. H., February 17, 1906.

ge height to water surface, 6.65 feet; gage height to bottom of ice, 5.15 feet; gage height to top of ice 6.67 feet; discharge, 2,070 second-feet.]

is-nce sec-on om ge.	Width below ice.	Area below ice.	Velocity.	Wetted Perimeter.	Hydraulic Radius.	Distance between sections.	Difference in elevation of water surface.	Slope.	Average hydraulic radius.	Average velocity.	*n*.
t.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*		*Feet.*	*Ft. per sec.*	
516	302	2,110	0.98	605	3.49	266	0.026	0.000098	3.12	1.04	0.030
250	340	1,890	1.10	685	2.76	150	.043	.000287	2.70	1.15	.042
100	329	1,730	1.20	659	2.63						

March 15, 1906.—The conditions were about the same as during ruary, but the strips of open water were considerably shorter and rower. There was no snow on the ice. Iron rods 4 or 5 feet long e driven into the bank to within about 6 inches of the water sur- in holes cut in the ice. These were located on each bank at sec- s 100 feet, 296 feet, and 516 feet upstream from the gage and the ation of the tops was determined by several series of levels. surements were then made from these points to the water surface a 2-foot rule. Independent observations were made at each it by two men, each man's set being averaged separately and the n of the two sets being finally used. The results were as follows:

Slope determinations and value of "n" on Connecticut River at Orford, N. H., March 15, 1906.

[Gage height to water surface, 5.62 feet; gage height to bottom of ice, 4.18 feet; gage height to top of ice 6.67 feet; discharge, 2,070 second-feet.]

Distance of section from gage.	Width below ice.	Area below ice.	Velocity.	Wetted perimeter.	Hydraulic radius.	Distance between sections.	Average hydraulic radius.	Average velocity.	Series.	Difference in elevation of water surface.	Slope.	n.
Feet.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Ft per sec*		*Feet.*		
									1	0.020	0.000091	0.030
516	295	1,800	0.83	592	3.04	220	2.67	0.90	2	.020	.000091	.030
									3	.024	.000109	.033
296	330	1,530	.98	662	2.31				1	.030	.000153	.030
						196	2.28	1.01	2	.031	.000158	.031
100	319	1,440	1.04	640	2.25				3	.030	.000153	.030

Conclusions.—The mean value of *n* for the February obsevations 0.036, and for the March observations is 0.031. The March series much the more reliable of the two.

DATA FROM OTHER SOURCES.

Up to the present time very little information has been publish on the flow of streams under ice cover, other than that gathered the United States Geological Survey.[a]

Raucourt made experiments on the Neva[b] at a point where it is 9 feet wide and of regular section, the maximum depth being 63 fe When the river was frozen over the maximum velocity (2 feet inches per second) was found a little below the middle of the deep vertical. It was somewhat less than double the velocity at the s face and bottom, which were nearly equal to each other.

The United States Engineer Corps[c] recently made some curre meter measurements of flow under ice cover on St. Marys River.

No details of the observations are given, but the general resu were as follows: (1) The location of the threads of mean velocity w found to be at 0.067 and 0.753 depth. (2) The maximum veloc was found to be at approximately 0.4 depth. (3) The friction caus by the ice was found to be 0.309 of that caused by the bottom.

Further measurements under ice cover on St. Marys River w made during 1905, but have not yet been reported for publication.

Considerable data on conditions in the frozen period, duration the frozen season, etc., may be found in the proceedings of the Int national Meteorological Congress, Chicago, 1893.[d]

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[a] Water-Sup. and Irr. Papers Nos. 76 (1903) and 95 (1904).

[b] Humphreys and Abbot, Physics and Hydraulics of Mississippi River, p. 190.

[c] Rept. Chief of Engineers for 1897, p. 4092.

[d] The four great rivers of Siberia: Bull. U. S. Weather Bureau No. 11, 1893.

CONCLUSIONS.

PRACTICABILITY OF WINTER ESTIMATES OF FLOW.

The classification of current-meter gaging stations on page 9 indicates that about one-sixth of them remain open during the winter and permit about the same degree of accuracy for winter estimates as for those of the summer; they can, therefore, be classed with stations south of the area subject to ice cover. About one-third of these stations usually have a smooth, permanent ice cover, and it is probably fair to assume that this is about the proportion at which winter estimates that will be fairly reliable can be made without too great cost. Undoubtedly there is a further number of stations where good estimates can be made if sufficient attention is given by the hydrographer, and particularly if an intelligent gage reader, with ability to note and sketch conditions affecting flow, is available.

Stations at dams, in general, give less trouble during the winter than current-meter stations, and this should be kept in mind where there is any question as to which form of station is preferable.

RECOMMENDATIONS AS TO METHODS.

The study of the flow of streams under ice cover is but just started, and in order to systematize the accumulation of data and to provide the material in convenient form for future use it is desirable that certain general methods be followed.

The methods of obtaining gage heights used should be as described on pages 21–23, and the observer should be especially encouraged to note any unusual conditions affecting flow, furnishing sketches where desirable. It should be kept in mind that what is desired is the *average* thickness of ice, distance from bottom of ice to water surface, etc., for the portion of the river near the gage, and that the hole cut in the ice should be so located as to give average results; preferably, several holes should be cut from time to time. The cost of current-meter measurements under ice cover can be kept within reasonable limits by employing laborers when necessary to cut holes in the ice, so as to utilize to better advantage the time of the hydrographer, and by using the two-point method of observations at 0.2 and 0.8 depth, with a few vertical velocity curves, if possible, for purposes of study. In case time is short a single observation at 0.5 depth will give fairly good results, the coefficient 0.88 being applied, or if a few vertical curves have been taken a closer value of the coefficient can be determined from them.

By following the above suggestions the total time required for a gaging will not be usually more than half a day, and the cost will be but little greater than that for a gaging under open-water conditions.

For depths less than 5 feet it is desirable to use the current n fastened to a rod for convenience in handling and in order tha depth may be reached; in fact, this method is generally preferab the use of a cable where depths and velocities are not too great.

Vertical velocity curves should be taken at typical points ir cross section when time permits just as for open water. These sh always be taken just before or after the two or one point observa at the point in question to give further information as to the accuracy of these methods, the observations by the point metho being incorporated in the vertical velocity curve.

Rating curves should be constructed in each of the two described on pages 43–46, and the method which seems to give the results should be used. Special efforts should be made to ol gagings for thin ice cover for the purpose of better defining the r curve or coefficient to use under such conditions.

It is believed that the methods previously indicated for disch measurements (pp. 22–24) will give results well within the degr accuracy consistent with winter estimates of flow, and that less need be spent hereafter on individual gagings. This will make it sible to give more attention to the study and completion of station ing curves—the direction in which the most effort should be expe in the immediate future.

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 187.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

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1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

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The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the nineteenth in Series M, the complete list of which follows (WS=Water-Supply Paper):

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CHARLES D. WALCOTT, DIRECTOR

WATER RESOURCES

OF THE

RIO GRANDE VALLEY IN NEW MEXICO

AND THEIR DEVELOPMENT

BY

WILLIS T. LEE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

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WATER RESOURCES OF THE RIO GRANDE VALLEY IN NEW MEXICO, AND THEIR DEVELOPMENT.

By WILLIS T. LEE.

INTRODUCTION.

The investigations described in this paper were undertaken for the purpose of gathering information which might aid in the development of the water resources of the Rio Grande Valley in New Mexico. Two general lines of observations were followed, one pertaining to underground waters and their utilization, the other to the storage and conservation of the surface waters. The work was done during the field seasons of 1904 and 1905 under the general direction of Mr. N. H. Darton. The area examined extends along the Rio Grande from the southern boundary of New Mexico northward to Santa Fe.

The valley of the Rio Grande, lying west of the Rocky Mountain uplift, extends in a north-south direction through a part of New Mexico which is characterized by comparatively small and more or less isolated mountain groups separated by basinlike depressions partly filled with rock débris. The valley is a part of the semiarid region of the southwestern part of the United States, in which the rainfall is insufficient for agriculture without irrigation.

A comparatively small amount of the water derived from the mountains to the north sustains a small but permanent flow in the river in the northern part of the region, but this water gradually disappears and the river bed in the southern part is often dry.

The Rio Grande is essentially a storm-water stream, subject to great and sudden floods. Within the area described only three permanent streams—the Rio Puerco, Rio Jemes, and Galisteo Creek—enter the Rio Grande, and their discharge, except in times of storm, is comparatively small. The rainfall in the region occurs principally in the form of violent showers or "cloud-bursts," which fill the dry stream courses with turbulent floods of short duration. When these showers occur simultaneously in many parts of the region they cause more or less destructive floods in the river. For these reasons the fertile irrigable lands along the river are sometimes unproductive

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for want of water and at other times crops are ruined because the fields are submerged or irrigation ditches destroyed by floods.

Much of the diminution in the volume of flow downstream is due to the fact that a large part of the water of the river sinks beneath the surface into the porous material of the valley bottom. Many of the tributary stream courses that are dry where they join the river contain flowing water in their upper reaches, the water sinking beneath the surface when it reaches the detrital material of the valley. The water entering the ground from the river and from the tributary streams is sufficient in volume to warrant its development for irrigation.

GEOGRAPHY.

RELATION TO OTHER REGIONS.

New Mexico consists of four general geographic provinces—the plains, occupying its eastern part; the Rocky Mountain province occupying its central part; the plateau province, in its northwestern part; and the basin range province, in its southwestern part. The Rocky Mountains proper terminate in northern New Mexico, but the general mountain uplift extends southward across the Territory as a succession of comparatively small mountain groups. These have not been generally recognized as parts of the Rocky Mountains, altho they belong to the same general system. The Rio Grande region lies between the Rocky Mountain province on the east and the plateau and basin range provinces on the west.

EASTERN MARGIN.

The crest of the Rocky Mountain uplift, consisting of the southern extremity of the Rocky Mountains proper, the Sandia and Montoso mountains, Sierra Oscura, San Andreas Range, and the Organ and Franklin mountains, form the eastern boundary of the area here described. The uplift becomes progressively lower toward the south, the maximum altitudes varying from 13,000 feet in the Rocky Mountains east of Santa Fe to 7,000 feet in the Franklin Mountains in the southern part of the region, and the minimum altitudes from 7,500 feet in Glorietta Pass near the northern end of the region to 3,700 feet at the southern end where the Rio Grande cuts through the uplift at The Pass. The rocks consist of granites and sedimentary rocks that range in age from pre-Cambrian to Tertiary.

WESTERN MARGIN.

The western margin of the Rio Grande Valley is much more irregular than the eastern margin, in both outline and altitude. It is formed by the Jemes Mountains at the north, by the Ladron, Socorro, Magdalena, and San Mateo mountains in the central part, and by the

report, but from the summit of the Potrillo Mountains the sandy plain appeared to continue southward unbroken as far as the eye could reach. It is probable that La Mesa is the northern extremity of the broad interior basin of northern Mexico, the lowest parts of which, containing undrained lakes, occur 25 to 50 miles south of the international boundary. At some former time this basin was probably occupied by a large lake, the northern extremity of which covered La Mesa.

SLOPES.

The greater part of the surface of the Rio Grande region is made up of long, corrugated slopes, extending from the bordering mountains to the river. East of the river the slope varies in length from 5 to 20 miles. Near Santa Fe it is 12 miles long and has an average gradient of 125 feet per mile. East of Albuquerque it is about 10 miles long and has a gradient of about 70 feet per mile, and east of Las Cruces it is 10 miles long and has a gradient of about 100 feet per mile. In places where the river is located near the mountains, as at the northern end of the Sandia and west of the Caballos Mountains (Pl. VI, *B*), the gradient is 250 to 300 feet per mile.

The slopes of the western part of the Rio Grande region are much more varied than those that lie east of the river. Some are short, steep, and deeply dissected; others are many miles in length and perfectly graded, and still others, like those drained by Arroyo Salado and Rio Puerco, are but slightly inclined.

The material exposed on the corrugated slopes consists of angular rock fragments derived from the mountains. These fragments vary in coarseness with the variations in the hardness of the rock from which they were formed and with the gradient of the slopes on which they are deposited. In general, they are large near the hills and on the steep slopes and small on the lower grades and near the foot of the slopes, where they are often found intermingled with sand and pebbles that have been rounded by stream action..

TERRACES.

The long slopes terminate more or less abruptly near the river in bluffs or terraces, two of which are more or less conspicuous throughout the Rio Grande region. The highest is not continuous. It is represented west of Santa Fe by the lava-capped detrital bluffs exposed in the canyon of Santa Fe Creek, where it forms a shelf 500 feet above a lower terrace and about 800 feet above the river, as shown in the Santa Clara sheet of the United States Geological Survey. West of Albuquerque it is represented by the broad, sandy plain upon which the lava flow from Albuquerque volcanoes rests, 500 feet above the lower terrace and 800 feet above the river. (See Pl.

II, *B*, and section D–D on Pl. III.) Near the southern end of tl region a similar relation occurs, the high detrital plain west of Cer Robledo being 500 feet higher than La Mesa and 800 feet higher th the river, as shown in the Las Cruces sheet of the United Stat Geological Survey. The ancient surface represented by these re nants apparently had the same gradient as the Rio Grande has the present time.

On either side of the river, at altitudes about 500 feet lower th the isolated remnants of the high terrace, are well-defined terrac which are practically continuous from White Rock Canyon to Paso. They are remnants of a surface that was formed principal by aggradation and later dissected by the river and its tributarie This surface is represented at Albuquerque by the wide shelf betwe the lava flow and the river, shown in the foreground of Pl. II, Farther south it is represented by the Jornada and La Mesa. (S sections of Pl. III.) The surface was formed, first, by the dep sition of river sand and gravel; second, by the erosion of prev ously deposited gravels and volcanic tuffs, illustrated in Pl. II, third, by lava flows, such as those near San Marcial (Pl. IV, *A*) a San Acacia, and, fourth, by the planation of upturned sedimenta rocks, like those exposed at the surface along the eastern base of t Caballos Mountains in the vicinity of Engle, shown in Pl. IX.

EROSION BASINS AND CANYONS.

Introductory statement.—Along the Rio Grande there are erosio basins, separated by rock canyons, as shown in Pl. I, and limited form and size by the character of the material in which they we excavated. These basins are parts of the valley of the Rio Gran that have been broadened on account of the easy erosion of unco solidated material while the narrower canyons were being cut in t hard rock.

Espanola Valley.—This valley extends from the head of Whi Rock Canyon northward beyond the region here considered. T southern end of the valley has been described as a possible reserv site,[a] and a contour map of it has been made. The valley is exc vated in unconsolidated sand, gravel, and rhyolitic tuff. The grav beds are exposed in bluffs several hundred feet high and are pr tected from erosion by the overlying igneous rock, consisting rhyolitic tuff and basalt flows. The depth of the sands and grave beneath the river is not known.

White Rock Canyon.—This canyon begins south of Espanola Valle at a point where the Rio Grande enters a narrow gorge about 20 mil in length. The canyon owes its existence to sheets of hard igneo

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1899–1900.

A. FACE OF TERRACE WEST OF CABALLOS MOUNTAINS.

Showing stratified sand and gravels overlain by rhyolitic tuff.

B. ALBUQUERQUE VOLCANOES AND LAVA FLOW.

Lower terrace, 300 feet above the river in the foreground. Lava flow, capping the detritus, 800 feet above the river.

rock, which protect the underlying sands and gravels. West of the river this rock is principally light-colored rhyolite, the color of which suggested the name White Rock Canyon, but east of the river it is basalt, of which there are two sheets, separated by a few feet of sand. The structure is indicated in a general way in fig. 2 and Pl. IV, *B*.

Near the mouth of the canyon a stream entering the Rio Grande from the east has carved a gorge, exposing about 400 feet of basalt. This gorge (Pl. IV, *B*), although comparatively small, illustrates the rugged character of the topography in the vicinity of White Rock Canyon.

Santo Domingo Valley.—This valley extends from the mouth of White Rock Canyon to a point 7 miles south of the Indian pueblo of Santo Domingo. It is 1 to 3 miles wide and contains about 13,000 acres of bottom land, which is owned mainly by the Santo Domingo Indians and has been irrigated by them for many years. The greater part of this land lies only a few feet above the bed of the river and is subject to frequent overflow.

San Felipe Canyon.—This is a short gorge separating Santo Domingo Valley from Albuquerque Valley. The canyon walls are composed of unconsolidated sand and gravel, capped by sheets of basaltic lava.

Albuquerque Valley.—This valley extends from San Felipe Canyon southward to Isleta, where it narrows on account of the basaltic lava which extends thence westward over a large part of the Sandia Mesa. The valley is about 35 miles long and 1 to 5 miles wide and comprises an estimated area of 70,000 acres of bottom land. It is terminated abruptly on either side by steep bluffs of sand and gravel forming the terraces previously described. The bluffs west of the valley consist of sand and clay, capped in places by sheets of basalt. Those to the east are composed of stratified sand overlain by coarse unstratified gravels separated from the underlying sands by erosional unconformities.

Isleta Narrows.—The constriction through which the river flows at Isleta is not properly a canyon. The broad Albuquerque Valley here narrows on account of the presence of the hard igneous rock of Isleta Volcano, an extinct volcanic cone west of the town. The lava occurs not only in the bluffs west of the river but extends nearly across the valley at the town of Isleta.

Belen Valley.—This valley, so named from the principal town within its area, extends from Isleta to San Acacia, a distance of about 45 miles, and contains an estimated area of 65,000 acres of bottom land. The Rio Puerco and the Arroyo Salado, the two largest tributaries of the Rio Grande, join the river in this valley. The Rio Puerco flows across the broad stretch of unconsolidated and horizontally bedded sand and gravel, locally known as Albuquerque Mesa.

It is a sluggish, muddy stream, practically impassable on account of quicksand, except at times of low water. The Arroyo Salado enters the valley through a canyon in the partly consolidated and upturned Tertiary strata illustrated in Pl. V, *A*.

San Acacia Gorge.—This is the narrows at the southern end of Belen Valley. The mesa east of the river near San Acacia is covered by a sheet of basalt, which originally extended farther northwestward across the present course of the Rio Grande. The river has cut thru an arm of this lava sheet, making a short narrow gorge, the walls of which, about 250 feet high, are composed of sand and gravel, protected by the cap of igneous rock.

The portion of lava left west of the river is less than one-half mile in length. West of this, and 75 feet higher than the river level, is a wide sand and gravel plain, which evidently marks the course of the Rio Grande previous to the time the river broke through the lava at the gorge. Still farther west the beds of loose sand and gravel give place to the Tertiary sediments shown in Pl. V, *B*.

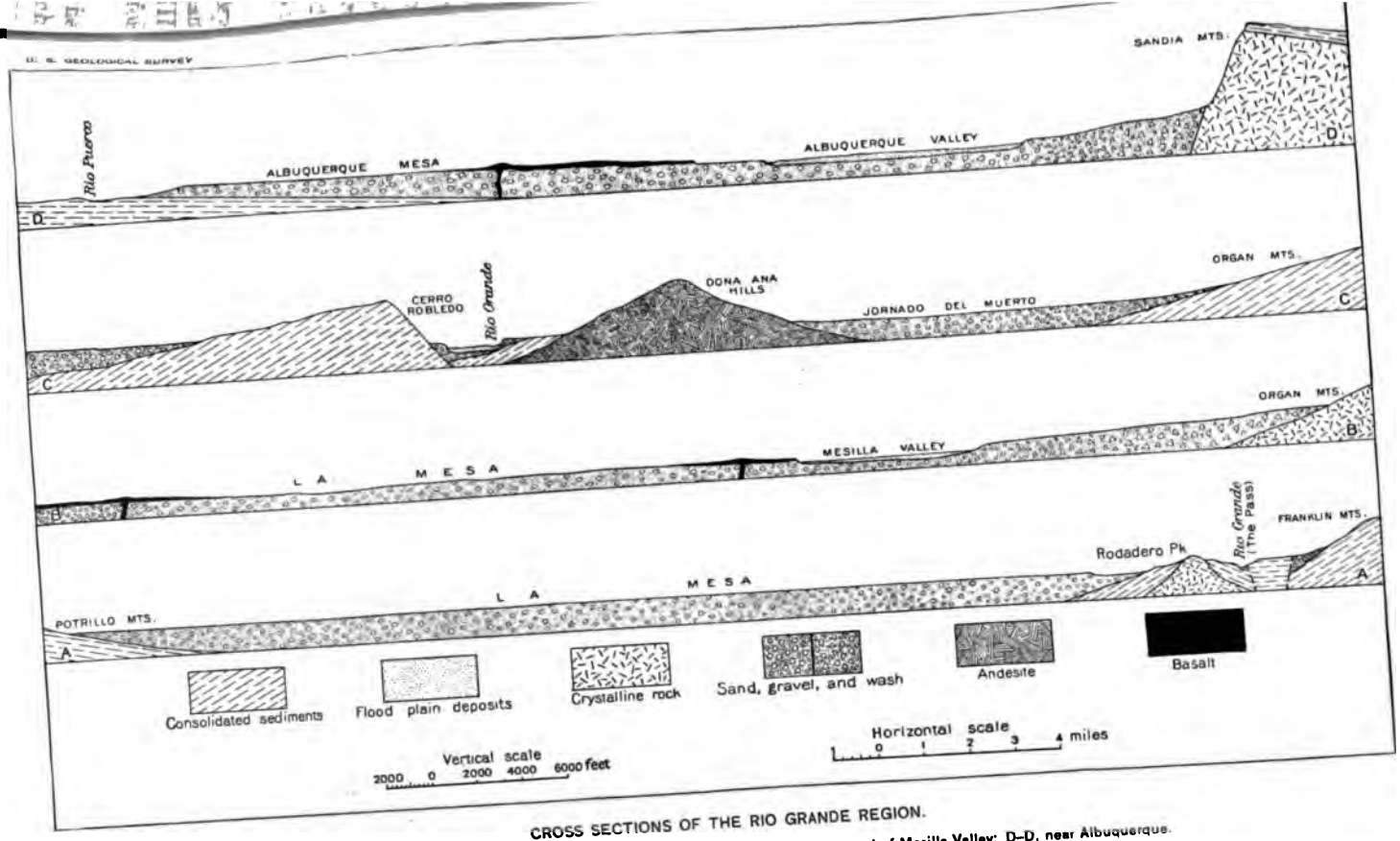
Socorro Valley.—This valley, so named from its principal town, extends from San Acacia Gorge southward to San Marcial, a distance of about 40 miles, and includes an estimated area of about 60,000 acres of bottom land. It is similar to Albuquerque and Belen valleys, except that the mountains on its sides are nearer and the corrugated detrital slopes correspondingly steeper and more eroded than those bordering the valleys previously described.

Engle Valley.—This valley extends from San Marcial to Elephant Butte, a distance of about 40 miles. This valley differs from the others described in being very narrow, as shown in Pl. I, and in its lack of bottom land. The northern half has been described and mapped as a reservoir site.[a] From this map it appears that the contour marking elevations 100 feet above the river incloses a strip of land varying in width from about 800 feet to 2 miles. The southern half of the valley is somewhat wider in places. According to the reports of the United States Reclamation Service the maximum area to be submerged in the Engle reservoir, described on pages 26–27, is about 38,400 acres, contained in a strip 40 miles long and about 1½ miles in average width.

Altho Engle Valley is cut in detritus, it is not so broad as the valleys to the north and to the south. West of the rock hills, near Elephant Butte, the detrital beds extend continuously southward (Pl. VIII) and seem to present an easy passage for the river, but it does not follow the course thus afforded.

Elephant Butte Canyon.—A few miles north of Elephant Butte the river leaves the detrital beds and enters a narrow rock canyon, which

[a] Twelfth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 263.



CROSS SECTIONS OF THE RIO GRANDE REGION.

A–A, at New Mexico-Mexico boundary; B–B, near Las Cruces; C–C, at northern end of Mesilla Valley; D–D, near Albuquerque.

it occupies thence southward to the end of the Caballos Mountains. This canyon is described in detail as the Engle dam site (see pp. 26–29) and need not be further discussed in this connection.

Las Palomas Valley.—This valley, extending from Elephant Butte to Rincon, a distance of about 50 miles, is much broader than Engle Valley. The bottom lands form a part of the irrigable area, 26,000 acres in extent, under the proposed Engle reservoir. The terrace bluffs bordering this valley are especially conspicuous. West of the river they consist of well-stratified sands and gravels, but east of the valley they are more varied in both form and composition, containing not only stratified sand and gravel, but volcanic tuffs, as shown in Pl. II, *A*.

Selden Canyon.—This canyon, extending from Rincon to the head of Mesilla Valley, a distance of about 18 miles, is not so uniformly narrow as some of the other canyons. At some places, as at Penasco Rock, where a dike crosses the course of the river, the canyon is narrow. At other places it broadens to considerable dimensions. It contains about 8,000 acres of bottom land.

Mesilla Valley.—This is the largest of the erosion basins of the Rio Grande region, extending from old Fort Selden southward to The Pass, a distance of about 50 miles. It has a maximum width of 8 miles and includes about 150,000 acres of bottom land, of which 100,000 acres are irrigable. It contains the principal body of land to be irrigated from the proposed Engle reservoir, and has been surveyed in detail by the United States Reclamation Service, as shown in Pl. X. The valley is cut in the unconsolidated sand and gravel, typically exposed in the bluffs, 300 feet or more in height, bordering La Mesa on the west.

As in the Elephant Butte region, the detrital bed in which Mesilla Valley is cut extends uninterruptedly southward, west of the rock hills near El Paso; but the river, instead of following this seemingly easy course, abandoned the detrital bed and cut a canyon through the hard rock ridge at El Paso.

El Paso Canyon.—This is a rock gorge through which the Rio Grande, formerly a stream of the interior basin region of New Mexico and Mexico, past and became thenceforth a part of the Gulf drainage. The character of this canyon and its relation to the mountain ridge and the ancient course of the river—La Mesa—is indicated in section A–A of Pl. III. Rock terraces at the same altitude as the surface of La Mesa indicate that after the river had formed a graded surface over the region, principally by building up its course, it found a way across the rock ridge at The Pass. The epoch of erosion that followed was not of sufficient duration to cut more than the narrow canyon in the hard rock of The Pass, although the broad Mesilla Valley was excavated at the same time.

El Paso Valley.—This valley is similar to Mesilla Valley in being a broad basin cut in unconsolidated sand and gravel. It lies outside of the Territory of New Mexico, and is therefore not properly included in this paper, although it contains part of the land included in the Rio Grande reclamation project. The valley has been described by Richardson[a] and by Slichter.[b]

GEOLOGY.

INTRODUCTION.

No attempt is made to discuss the geology of the Rio Grande region further than is necessary to give an understanding of the physical conditions likely to affect the storage of the surface waters and the occurrence and development of the underground waters; but in order to describe these conditions some knowledge of the rocks is necessary. Three kinds of rock are recognized in this report. The first consists of granites, gneisses, and consolidated sediments, including sandstones, limestones, and shales. The second consists of unconsolidated sediments or detritus of comparatively recent origin, including river sands and gravels and mountain wash. The third comprises effusive rocks, mainly of Tertiary and Quaternary age.

ROCK FORMATIONS.

CONSOLIDATED SEDIMENTS.

The older sedimentary rocks of the Rio Grande region include strata that range in age from Algonkian to Cretaceous and that are well exposed throughout the area described. These, together with the underlying granites, form the rock basins that contain the water-bearing formations and to some extent are themselves water bearing. The consolidated sediments have special importance near Elephant Butte, where the Rio Grande cuts a sharp gorge through them at the Engle dam site, and near El Paso, at the site of the proposed International dam.

UNCONSOLIDATED SEDIMENTS.

Unconsolidated material, consisting of clay, sand, and water-worn gravel, occurs generally in the lowlands along the river, in the terraces on either side of the Rio Grande Valley, in the central part of the Jornada del Muerto, and in La Mesa, west of Mesilla Valley. The slopes lying between the river and the mountains consist largely of angular rock débris, derived as wash from the mountains.

The older detrital beds are partly cemented, but the younger ones are wholly unconsolidated and allow water to pass freely through them

[a] Richardson, G. B., Reconnaissance in trans-Pecos Texas: Bull. Univ. Texas No. 23, 1904, pp. 95–108.

[b] Slichter, Charles S., Observations on the ground waters of the Rio Grande Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 9–51.

A. LAVA-CAPPED MESA AT SAN MARCIAL.

The sheet of basalt resting upon the sand and gravel is the edge of the great flow covering the north end of the Jornada del Muerto.

B. SIDE GORGE AT THE ENTRANCE TO WHITE ROCK CANYON, NEAR ESPANOLA DAM SITE.

Showing columnar basalt in the foreground, and the rhyolite west of the river in the background.

he detritus has a great, though unknown thickness. A well at Santa e penetrates it nearly 1,000 feet; another at Sandia, N. Mex., 893 feet; ne at Lanark, west of Mesilla Valley, 945 feet; and one in a neighbor-ıg basin,[a] near El Paso, 2,285 feet, but in none of these wells has bed ock been reached. Where the older and partly cemented beds have een upturned and exposed to view in Arroyo Salado, they have an bserved thickness of several thousand feet. Their character is indi-ated in Pl. V, *A*, *B*. The younger or uncemented sands and gravels re well exposed in the terraces on either side of the river.

IGNEOUS ROCKS.

The igneous formations that are important in a discussion of the ater supply are principally of Tertiary and Quaternary age, and ccur in the form of massive flows, beds of tuff, volcanic necks, dikes ıd sheets, and crater cones. The older effusive masses, consisting of ıdesites, rhyolites, and other rocks closely related to these, occur in ore or less isolated masses at many places throughout the Rio Grande gion and are perhaps best represented by the thick beds of tuff on e eastern slope of the Jemes Mountains in the northern part of the o Grande region, by the Socorro Mountains and Cerro Magdalen in e central part, and by the Dona Ana Hills in the southern part. eir formation antedates the accumulation of at least the upper rt of the detritus as fragments of the rock are contained in the rital beds.

The younger igneous rocks consist of dark-colored basalts, occurring inly in sheets capping the detritus and in crater cones which retain ir original form in great perfection, as shown in Pl. VI, *A*. Basaltic k also occurs in dikes and volcanic necks penetrating the older ks. Among the more conspicuous sheets capping the detritus may mentioned those west of Santa Fe, through which the river has ded White Rock Canyon, those covering parts of the mesa west of uquerque (see Pl. II, *B*), the San Marcial flow (see Pl. IV, *A*,) and basalt flows of La Mesa west of Mesilla Valley. The dikes and vol-ıic necks become important in the vicinity of the Engle reservoir l. IX), where they will probably supply building stone for the posed dam.

STRUCTURE.

GENERAL CHARACTERISTICS.

The geologic structure of the Rio Grande region is complicated, and ıch detailed investigation is necessary before it can be adequately scribed. The main structural features, however, are known in a neral way. Great synclines, such as the Jornada del Muerto, occur,

[a] Richardson, G. B., Reconnaissance in trans-Pecos Texas: Bull. Univ. Texas No. 23, 1904, p. 96.

and monoclinal mountains, formed by faulting and the tilting of crust blocks. The rocks thus flexed and faulted are mainly of pre-Tertiary age, but the Tertiary beds are strongly upturned in places, indicating that some crustal movement took place after these beds were formed. (Pl. V, A). The older valleys of erosion and the troughs formed by the tilted blocks have been partly filled with unconsolidated detritus consisting of sands, waterworn gravels, and angular mountain wash.

EASTERN BORDER.

The eastern part of the Rio Grande region is occupied by the Rocky Mountain uplift, which extends through central New Mexico. The southern end of the Rocky Mountains, terminated at the south by Glorieta Pass, is a granitic mass upon which lie strata that dip away from it to the east, south, and west. But south of this pass the underlying granite is covered, more or less completely, with sedimentary rocks dipping in various directions. The strata of Glorieta Mesa incline toward the south, and those of the Sandia Mountains, the Manzano Range, and Sierra Oscura toward the east. The strata of Chupadera Mesa are nearly horizontal, while those of the San Andreas Range and the Organ and Franklin mountains dip toward the west. Numerous faults occur, with displacements measured in hundreds of feet and several with displacements of thousands of feet.

WESTERN BORDER.

The western part of the Rio Grande region is less mountainous than the eastern part, and a greater proportion of it is covered with detritus, which obscures the structure to a large extent. In the Rio Puerco Valley strata dip to the east and are believed to pass beneath the Rio Grande Valley, while strata of the same geologic age occur in the Sandia Mountains, several thousand feet above the Rio Grande Valley, the difference in elevation being due to faulting along the western face of the Sandia Mountains and the eastward tilting of the Sandia block, as indicated in section D–D of Pl. III. On the other hand, the crust block forming Sierra Ladron, a few miles south of Rio Puerco, has been tilted steeply to the west.

In the western part of the region many of the mountain groups, such as Jemes and Socorro mountains and Cerro Magdalen, are composed principally of effusive rock.

CENTRAL AREA.

The structure of the Rio Grande region is best shown in the central portions, where the river has removed the detritus in many places, exposing the consolidated rocks. The Caballos and Fra Cristobal ranges, forming the western limb of the Jornada syncline, are cut off

TERTIARY STRATA IN ARROYO SALADO AT THE BASE OF SIERRA LADRON.

B. CANYON IN TERTIARY SEDIMENTS WEST OF SAN ACACIA, N. MEX.

abruptly on the west by great faults which are plainly exposed and traceable for longd istances. (See Pl. VII.) Cerro Robledo furnishes a characteristic type of structure. (See Pl. III.) East of the river Carboniferous limestone, dipping westward, passes beneath the Rio Grande Valley. The same limestone occurs in the hills to the west 2,000 feet above the river, the difference in altitude being due to faulting and the tilting of the Cerro Robledo block.

Displacements by faults much greater than that at Cerro Robledo are evident at a number of places. The western face of the Caballos Mountains (see Pl. VI, *B*) and the Fra Cristobal Mountains (Pl. VII) are fault scarps, and Cerro Cuchillo is an excellent example of a tilted block. With the exception of the Jornada del Muerto, the Rio Grande region may be properly said to consist of a series of block mountains with troughlike depressions intervening between them.

TOPOGRAPHIC DEVELOPMENT.

EROSION.

Altho the elevations and depressions constituting the Rio Grande region are due principally to crustal deformation, the topography has been more or less modified by erosion and deposition. Many of the mountain slopes are precipitous and show little modification by erosion, as illustrated in the Caballos Mountains. (Pl. VI, *B*.) Other slopes are comparatively mature. Along the eastern base of the Caballos and Fra Cristobal ranges, particularly in the vicinity of Engle, the stratified rocks dipping eastward beneath the Jornada have been practically base-leveled over a considerable area. Whether the base-level extends beneath the Jornada generally, as stated by Keyes,[a] or is local, can only be conjectured at the present time, as the older rocks within the syncline are exposed over a comparatively limited area, being for the most part buried to unknown depths by detritus.

SEDIMENTATION.

Tertiary.—The older portions of the detritus contained in the rock basins consist of well-stratified beds of sand, gravel, and mountain wash, more or less faulted in places and otherwise disturbed by crustal movements. They are undoubtedly of Tertiary age. In other places sediments, apparently of Tertiary age, are not separable at present from the younger or Quaternary deposits.

Quaternary.—The unconsolidated sands, gravels, and "wash" covering the greater part of the Rio Grande region is of Quaternary age and occurs in at least two distinctly separable formations. The more extensive one, locally known as the mesa gravels, occurs in the terraces along the river and forms the corrugated slopes lying between

[a] Keyes, C. R., Water-Sup. and Irr. Paper No. 123, U. S. Geol. Survey, 1905, p. 25.

the river and the bordering mountains. The second occurs in the flood plains in all of the erosion basins previously described. In the Jornada del Muerto and La Mesa the sand and gravel beds belonging to this formation are not dissected by erosion, but lie practically as they were deposited, at an altitude 300 to 350 feet above the present bed of the river.

The mesa gravels originally filled the basins to altitudes represented by the terraces, and in them the erosion basins were cut. The depth to which these were excavated and later filled is not definitely known, but the general relations of the various gravel beds to each other and to the rock basins containing them are illustrated in fig. 1.

TERTIARY AND QUATERNARY HISTORY.

SURFACE DEFORMATION AND FIRST VOLCANIC ERUPTION.

The crustal movements that produced the structural and geographic features described began at the commencement of or sometime during the Tertiary period with the formation of monoclinal mountains and troughlike intermontane valleys. About the same

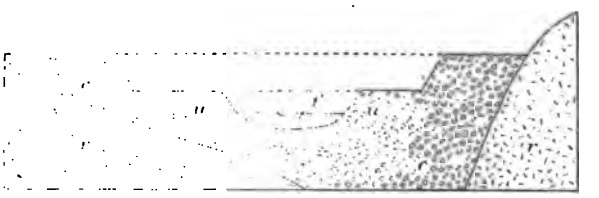


FIG. 1.—Sketch section illustrating the detrital deposits of Rio Grande Valley. *r*, Rock basin; *c* detritus of the higher terrace; *u*, detritus of the lower terrace; *f*, flood-plain deposits.

time great masses of andesite and rhyolite were extruded, remnants of which are now found in the Jemez Mountains, the Socorro Mountains, the Dona Ana Hills, and elsewhere. This deformation and volcanic activity evidently occurred late in the Tertiary period, as Tertiary strata are upturned and in places intersected by rhyolite.

FIRST ACCUMULATION OF GRAVELS.

The structural troughs between the tilted mountain blocks formed natural lodgment areas for sediment. It can not be stated at present whether the sediments are partly of lacustrine origin or wholly subaerial, nor is their maximum thickness known, but well records indicate a thickness of thousands of feet. The material exposed in the terraces and penetrated by the shallow wells, consisting mainly of coarse sand and gravel, is presumably of river origin, but some of the deep wells penetrate thick beds of sandy clay, possibly of lacustrine accumulation. The surface of this first gravel accumulation is preserved in a number of places, where it forms the upper terrace, 800 feet above the river, described on page 11.

A. SANDIA VOLCANO, WEST OF ISLETA, N. MEX.

A volcanic cone of recent origin, composed of basaltic cinders.

B. CABALLOS MOUNTAINS.

Showing the western escarpment and the corrugated alluvial slope at its base.

SECOND VOLCANIC ERUPTION.

After the depressions had been filled to altitudes represented by the upper terrace, extensive sheets of basalt were outpoured over the sands and gravels. In the lava fields west of Santa Fe, and in those near Bernalillo, two sheets of basalt occur, separated by a few feet of gravel, as shown in fig. 2. West of Albuquerque (Pl. II, *B*), and also in the extensive lava fields west of Isleta, the older sheets apparently belong to this epoch of eruption, and it is probable that many of the older masses of basalt in other parts of the Rio Grande region were extruded at about the same time.

FIRST EPOCH OF EROSION.

The second volcanic eruption was apparently accompanied by some change, possibly climatic, which caused the Rio Grande to erode its channel. During this epoch the river probably flowed through the Jornada del Muerto south of San Marcial, across La Mesa west of El Paso, and southward into the basin region of northern Mexico, eroding a valley 10 to 20 miles wide.

Ancient course of the Rio Grande.—Many facts point to the inference that the ancient course of the Rio Grande was not the same as its present course south of San Marcial. Some of the data leading to this inference have been given and others will be presented in the following paragraphs. Briefly stated, the facts are these:

The Jornada and La Mesa have the geographic position, form, surface elevation, and gradient that would be expected in a débris-filled valley; they contain unconsolidated sands and gravels as deep as wells have penetrated; their surface elevations and gradients indicate that they are parts of a graded surface that formerly extended throughout the Rio Grande region and is now represented north of San Marcial by the low terrace previously described, this ancient surface having the same gradient as that of the river at the present time.

At the point where the river leaves this old valley the surface is covered by an extensive basalt flow (the San Marcial lava sheet, covering about 160 square miles) resting on sand and gravel beds. The lava is not eroded at the surface and is covered only by wind-blown sand. Large quantities of loose shifting sand lie immediately north of the lava beds.

Engle and Las Palomas valleys are much narrower than the other erosion basins, and are cut in detritus which contains gypsum in places. The beds are cemented to some extent, and are associated with rhyolite, presumably much older than the basalt and its underlying detritus at San Marcial.

The measure of consolidation, presumably due to difference in age, is indicated in the size of the erosion basins. While the river cut can-

yons in hard rock it excavated narrow valleys in the cemented de tus west of Caballos and Fra Cristobal mountains and broad bas like Socorro and Mesilla valleys in the unconsolidated detritus to north and south.

From these facts the inference is drawn that the ancient Rio Gran flowed through the Jornada and La Mesa into the interior basin Mexico, and that in comparatively recent geologic time chang occurred which turned it out of its valley and away from the interi basin toward the Gulf of Mexico.

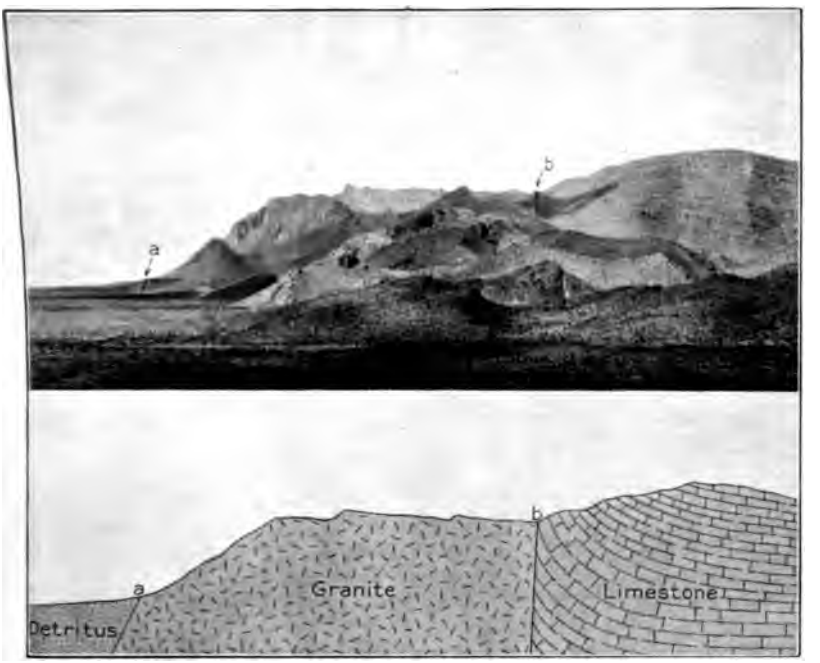
SECOND ACCUMULATION OF GRAVELS.

During the second epoch of deposition the river filled its valley wit sand and gravel to the grade represented by the lower terrace (*uu* of fi 1) and by the surface of La Mesa and the Jornada del Muerto. In L Mesa the ancient valley is about 20 miles wide and the filling is mainl fine sand near the surface and somewhat coarser sand and gravel b neath. In the Jornada del Muerto the filled valley is narrower a the material is coarser, many of the pebbles having a diameter of se eral inches. In Albuquerque Valley the quantity of filling during t epoch is much less than in La Mesa and the Jornada, and is best re resented by the coarse gravel deposits of the bluffs near Albuquerq Still farther north, in Santo Domingo Valley, near the northern end the Rio Grande region, the deposits are very limited, and the ri here was apparently employed mainly in broadening its valley.

The graded surface formed by the river during this epoch was o mainly of erosion in Santo Domingo Valley, where a broad shelf w cut 500 feet below the surface of the older gravels; one formed par by erosion and partly by deposition in Albuquerque Valley; and o mainly of deposition in the Jornada and La Mesa. Throughout t Rio Grande region this surface, represented now by the terrac bluffs, is about 300 feet above the river, except where it has been c down by later erosion.

THIRD VOLCANIC ERUPTION.

Near the close of the second period of sedimentation extensive v canic disturbances occurred throughout the Rio Grande region, resu ing again in the outpouring of great sheets of basalt. The most co spicuous of these are near San Marcial (Pl. IV, *A*) and on La Mesa w of Mesilla Valley. The San Marcial flow, covering about 160 squ miles, was outpoured on the Jornada del Muerto, then occupied by Rio Grande, and probably created a dam that formed a tempor lake in which were accumulated the great quantities of sand found the Jornada north of the lava sheet.



A. WESTERN FACE OF THE FRA CRISTOBAL MOUNTAINS.

Showing two faults, a and b.

B. FAULT PLANE AT THE WESTERN BASE OF FRA CRISTOBAL MOUNTAINS.

Showing near view of a, above.

DIVERSION OF THE RIO GRANDE.

There is no evidence that the river ever flowed over the San Marcial lava sheet. The surface of this sheet is not eroded and, so far as observed, is devoid of foreign matter except a small amount of wind-blown sand. The volcanic dam, aided possibly by surface movements accompanying the volcanic eruptions, evidently diverted the river from its old valley in the Jornada to a new course for a distance of about 100 miles west of the Caballos and Fra Cristobal mountains. At Dona Ana it returned to the old débris-filled valley, which it crossed diagonally and abandoned again at El Paso.

Several phenomena which otherwise are difficult to explain are made clear by a recognition of this change in the course of the river.

First, as previously stated, the surface of the Jornada between San Marcial and Mesilla Valley has an average gradient of 4.5 feet per mile, which is practically the gradient of the river at the present time.

Second, the detrital beds cut by the river west of the Fra Cristobal and Caballos mountains are associated with rhyolite, apparently extruded at the same time as the rhyolites previously described as of Tertiary age, indicating that the detritus is older and probably more difficult to erode than the loose sands and gravels that were deposited later.

Third, near Rincon, and again in Selden Canyon, gypsum was noted in the detrital beds, but nowhere was any indication of gypsum found in the mesa gravels referable to the epoch in which the Jornada and La Mesa were filled.

Fourth, as previously stated, Engle Valley is much narrower than the other erosion basins formed at the same time—as, for example, Mesilla and Belen valleys, which have been excavated from river sands and gravels known to be of recent origin. This difference is due, no doubt, to the greater resistance to erosion of the older detritus.

SECOND EPOCH OF EROSION.

The volcanic eruptions and the change in the course of the river were followed by a second epoch of erosion. In again eroding a valley, the river worked principally in the unconsolidated sands and gravels previously deposited, excavating the erosion basins, but at a number of places where it had wandered from its old course it cut its channel in hard rock, forming the various canyons. The result is the succession of comparatively broad basins and short rock canyons that characterize the Rio Grande region.

ACCUMULATION OF SILT.

The second epoch of erosion was followed by the deposition of the silt and sand that now form the flood plains of the erosion basins. The depth of this third valley filling is not great. Borings indicate a maximum depth of 85 feet at the International dam site in El Paso Canyon and of 72 feet at the Engle dam site, near Elephant Butte. The depth within the basins probably does not differ greatly from that in the canyons, but this can not be stated positively.

The well records given in the section on underground waters indicate that the mesa gravels (*uu* of fig. 1) are probably encountered at depths of 30 to 80 feet. The first "cemented sand" in the Albuquerque well (p. 34) is presumably a hardened layer of the Tertiary beds and the gravel beds in the Mesilla Valley wells (pp. 41-46), encountered at depths of 30 to 75 feet, are interpreted as belonging to the mesa gravels. The depth of flood-plain deposit thus indicated corresponds well with the known depth of filling in the canyons.

The deposition of sand and silt in the erosion basins causes frequent changes in the course of the river, so that bayous, sloughs, and oxbow lakes are common in the bottom lands. This is well illustrated in Mesilla Valley (Pl. X), where many abandoned courses occur, particularly near the southern end, some still occupied by streams and others nearly filled with silt. A characteristic change in the channel of the river occurred in 1905 near the head-gate of Las Cruces canal, at the northern end of Mesilla Valley. During the spring floods of that year the river broke through the narrow neck of land on the western side of the valley, leaving the head-gates about a mile from the new channel.

B. M. Hall, supervising engineer of the United States Reclamation Service, in charge of the Rio Grande project, has made computations of the amount of silt carried by the Rio Grande. He arrives at the conclusion that the river carries, on the average, 14,580 acre-feet of mud a year, or enough when dry to cover 14,580 acres 1 foot deep. The computation, although made for the purpose of estimating the time required to fill the reservoirs with mud, is useful in this connection in indicating the possibilities of rapid accumulation wherever opportunity is offered.

During times of flood the river naturally carries its maximum amount of silt, which is thus admitted to the sloughs and overflow districts and gradually fills them to the common level of the flood plain. A similar action takes place in the irrigation ditches, which rapidly fill with silt. Some of the older ditches have thus been built up many feet above the level at which they were originally constructed.

RESERVOIR SITES.

INTRODUCTORY STATEMENT.

The alternation of erosion basins and rock canyons in the Rio Grande Valley is especially favorable for the construction of reservoirs and the conservation and use of the flood waters of the river. Available dam sites occur in the canyons, while the broad basins are suitable for storage reservoirs or for irrigation, according to location and character. Several reservoir sites have been selected and the two most promising ones—the International reservoir, at the southern end of the region, and the Engle reservoir, west of the Fra Cristobal Mountains—have been investigated in detail.

INTERNATIONAL RESERVOIR.

The proposed International reservoir is located at the southern end of Mesilla Valley and was designed by its promoters to store water to be used in El Paso Valley, which lies partly in Texas and partly in Mexico. The dam site is in the canyon about 4 miles north of the city of El Paso.

El Paso Canyon is a narrow gorge carved in solid rock, consisting of Lower Cretaceous sediments and eruptive rocks. The strata have been considerably fractured and faulted. Rodadero Peak, to the west, has a granitic core overlain by highly inclined Lower Cretaceous sandstones, shales, and limestones. East of the river the strata lie more nearly horizontal, while in the Franklin Mountains, still farther to the east, strata older than Cretaceous dip steeply to the west. The shattered and faulted state of the rock is apparently the only geologic condition unfavorable to El Paso Canyon as a good dam site. The gorge is narrow, the rock abutments are firm, and the depth to bed rock in the channel is not prohibitive, as it is found at a maximum depth of little more than 80 feet. The site has been described in detail in the report of the International (Water) Boundary Commission.[a]

Although the dam site of the proposed reservoir is a good one, geologic conditions are not favorable to the successful storage of water in the southern part of Mesilla Valley. As previously pointed out, the old gravel-filled valley of the Rio Grande passes southward into Mexico west of Rodadero Peak. The water of the reservoir would be impounded in the basin eroded from the unconsolidated gravels of the old valley fillings and would undoubtedly escape to some extent through these gravels until such time as they might become impervious from silting. It is an open question how much time would elapse before this silting would become effective in preventing leakage.

[a] Proceedings International (Water) Boundary Commission, United States and Mexico, 1903, vols. 1 and 2.

ENGLE RESERVOIR.

LOCATION.

The proposed Engle reservoir site is located in Engle Valley, west o the Fra Cristobal Mountains, and is best reached from Engle, a smal town on the Atchison, Topeka and Santa Fe Railway. The site o the proposed dam is in the rock canyon near Elephant Butte, a larg volcanic neck standing near the river, as shown in Pl. IX.

ROCK FORMATIONS.

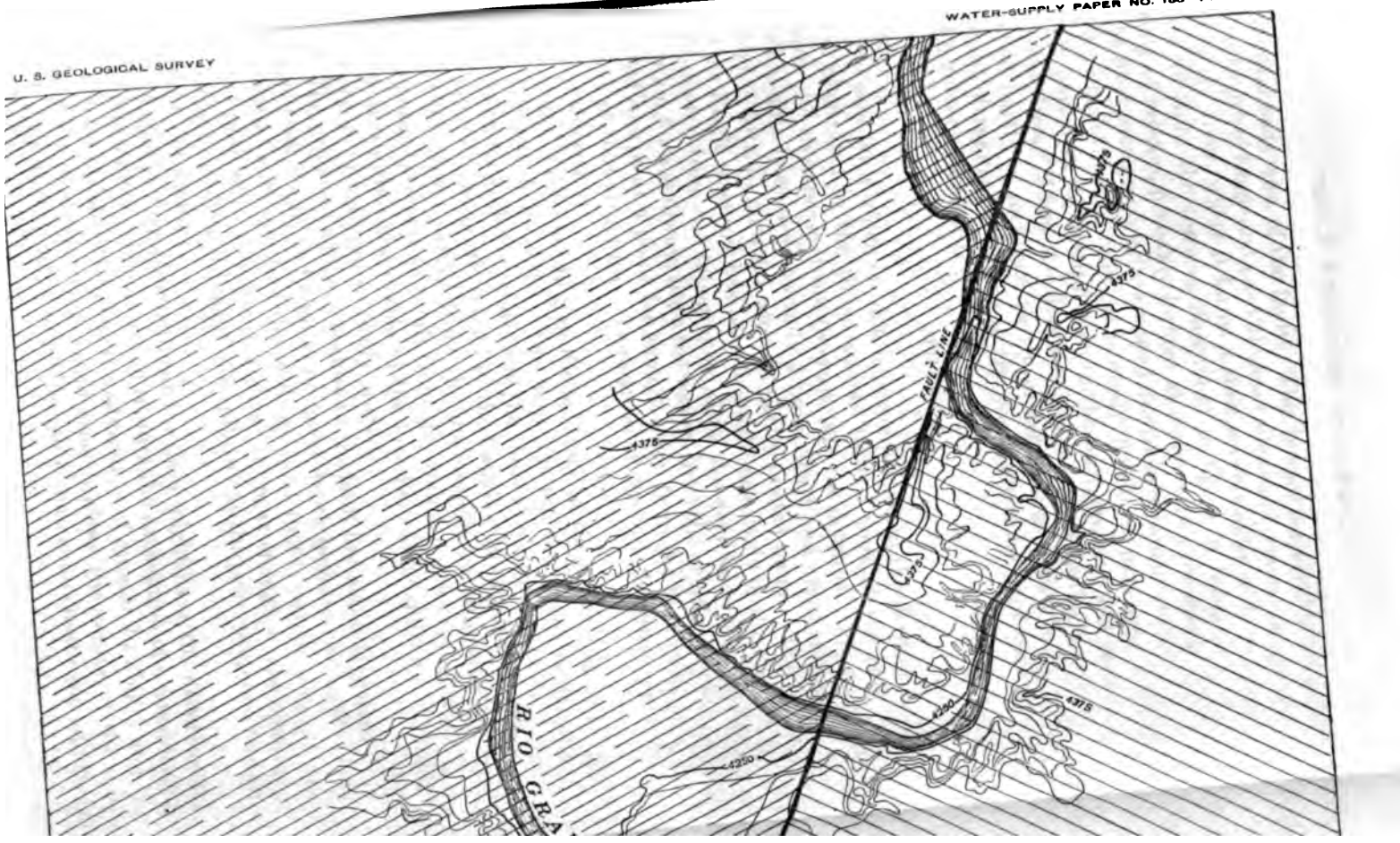
The rocks near the proposed reservoir are of several kinds. In th mountains, a few miles distant, there are pre-Cambrian granites over lain by Paleozoic and Mesozoic sandstones, shales, and limestones and in the valleys there are Tertiary and Quaternary sands, gravels and eruptive rocks. The rocks that will probably be of economi importance in building the proposed dam are the Carboniferous lime stones and shales of the Caballos Mountains, the Cretaceous sand stones forming the abutments of the dam and comprising the greate part of the area mapped in Pl. VIII as "rock," also shown in the fore ground of Pl. IX, and the basaltic rock found in Elephant Butte an in the dikes of that vicinity, as well as in the lava flows and crate cones on the Jornada to the east, shown in the distance in Pl. IX.

The unconsolidated sands and gravels of Tertiary and Quaternar age are mainly of negative importance, since they form the floor an confining walls of the reservoir and endanger leakage.

STRUCTURE.

The geologic structure in the vicinity of Elephant Butte has bee described in a general way under the heading "Central area" (pp. 9–16) where it is shown that the face of the Fra Cristobal and Caballo mountain ranges (see Pl. VII) are due to faulting and that the detri tal valleys are due to the filling of the troughs thus formed with roc débris. The structure is illustrated in detail in the Elephant Butt area, a map and cross section of which are given in Pl. VIII. Th fault at the western base of the mountains passes through this region separating the unconsolidated detrital beds to the west from the roc formations to the east. The rocks, consisting mainly of Uppe Cretaceous sandstones and shales, are more or less fractured nea the fault and incline in a general easterly direction, the dip varyin from about 10° to 90°.

The high lava-covered surface, shown at the right in the sectio Pl. VIII and in the distance in Pl. IX, is the western edge of the Jornad del Muerto. About 300 feet below this level and 150 feet above th river a broad terrace is cut in the sandstones east of the fault line and i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the detrital beds west of the fault. This terrace is traceable throughout the length of Engle and Las Palomas valleys and is most conspicuous west of the river, where it forms a shelf several miles wide in places. It differs from the terraces illustrated in fig. 1 in being a surface mainly of erosion, probably formed at a time when the down cutting of the river was temporarily arrested, for some reason as yet unknown, during which time the river cut laterally, flowing in part over the rock and in part over the detrital beds to the west, crossing and recrossing the fault line. When the river resumed its down cutting it eroded a canyon partly in rock and partly in detritus, as shown in Pl. VIII, instead of taking the course to the west, where no hard rock would have been encountered.

SPILLWAY.

The ease with which erosion is accomplished in the detrital beds is well illustrated in the three oxbows formed west of the fault line, where the river passes from the rock into the detritus. The southern and middle bows are now only 2 miles apart and are separated by a ridge of detrital material already partly eroded away. The spillway of the Engle reservoir has been located tentatively in this depression. Considered from the topography alone the depression is an excellent location for a spillway, since the waters from the overflowing reservoir would escape at a point far enough away from the dam to insure the safety of that structure. The nature of the rock, however, must also be considered.

A small valley heading in the spillway at the summit of this ridge is indicated in Pl. VIII. The map was not completed to the south but a similar valley extends from the spillway southward to the bend in the river at the northern end of the Caballos Mountains. These valleys have been carved from the unconsolidated sediments by such temporary streams as result from the drainage of a very small area, a fact distinctly unfavorable to the location of the spillway of a great reservoir in material so easily eroded.

The proposed spillway is close to the fault line and it is possible that solid rock might be found at no great depth beneath the surface. In a small valley south of the spillway sandstones occur in a nearly vertical position. But whether these are near enough to the surface to warrant the establishment of a spillway at the point proposed remains to be determined.

A spillway constructed near the dam might have the disadvantage of greater cost, since it would require the excavation of a considerable amount of hard rock, but the advantage of greater durability and the absence of danger from rapid erosion along the course of the overflowing waters would probably more than compensate the additional cost.

CONSTRUCTIONAL MATERIALS.

Building stone.—Several varieties of building stone are found within the Elephant Butte area. Massive limestones and red sandstones of Carboniferous age occur in the Caballos Mountains, the northern end of which is 1½ miles distant from the site of the proposed dam. Massive sandstones of Upper Cretaceous age occur at the dam site in the walls of the canyon. Field observations indicate that these will probably prove valuable for purposes of construction. But the strongest and most durable as well as the most accessible building stone is the basalt of Elephant Butte, which occurs close to the dam site. (Pl. VIII.)

Cement material.—The problem of procuring cement for the construction of the dam is important. Cement must either be hauled about 12 miles from the nearest railway station or manufactured near the dam site. Cement material is available in the Elephant Butte area. In the northern end of the Caballos Mountains, at the mouth of Mescal Canyon, limestone and shale occur in abundance. Samples of each were taken and were analyzed in the laboratory of the United States Reclamation Service at Berkeley, Cal. The samples were not selected by one familiar with the technical requirements of cement manufacture, and probably more suitable material may be found. The analyses of these samples, given below, must be regarded as preliminary, but indicate that good cement materials may be found near the dam site.

Analysis of limestone from the northern end of Caballos Mountains.

[C. H. Stone, analyst.]

Silica (SiO_2) and insoluble matter	7.94	Soda (Na_2O)	0.28
Alumina (Al_2O_3) and ferric oxide (Fe_2O_3)	0.80	Sulfur trioxide (SO_3)	0.30
Lime (CaO)	44.99	Carbon dioxide (CO_2) calculated to combine with CaO	39.29
Magnesia (MgO)	1.23		95.30
Copper oxide (CuO)	0.38	Moisture	0.11
Potassa (K_2O)	0.09		

Analysis of shale from the northern end of Caballos Mountains.

Silica (SiO_2)	63.74	Soda (Na_2O)	Undet.
Ferric oxide (Fe_2O_3)	6.44	Potassa (K_2O)	Undet.
Alumina (Al_2O_3)	17.33	Sulfuric trioxide (SO_3)	Trace.
Lime (CaO)	5.51	Ignition loss (H_2O, CO_2)	
Magnesia (MgO)	1.86		94.88

RATIONAL ANALYSIS.

Clay substance	27.20
Quartz	3.25
Feldspathic detritus	69.55

ENGLE DAM SITE.

Showing Elephant Butte at the right, the edge of the Jornada del Muerto in the distance, the tilted Cretaceous sandstones in the foreground, and the dry bed of the Rio Grande.

The ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$ =2.6 is well within the limits of the ratio >2.3 or <3.6. The MgO content is low, and the absence of SO_3 makes this material one of the purer clays, considered from a technical point of view.

Coal.—Coal has been found in Mescal Canyon about 4 miles south of Elephant Butte. Where exposed at the surface the beds are only a few inches thick, but are associated with a considerable amount of carbonaceous shale. The coal is in the same formation that contains valuable deposits of coal at Carthage and other places farther north, but the prospects have not been developed.

SAN ACACIA RESERVOIR.

The narrow gorge at San Acacia is one of the proposed dam sites of the Rio Grande region. The broad Belen Valley, to the north, narrows abruptly at this point on account of the sheet of basalt which here covers the detritus. Measurements made at this point by Mr. R. H. Chapman, of the United States Geological Survey, indicate that a dam 50 feet high would be 1,200 feet in length and would flood about 18 square miles to an average depth of 25 feet, thus impounding about 288,000 acre-feet of water. A higher but longer dam might be constructed, but the maximum possible height is less than 75 feet above the river bed, the limiting factor being the broad sand gap to the northwest, the surface of which is about 75 feet above the river level.

Probably the most serious objection to San Acacia Gorge as a dam site is found in the nature of the rock. The hard basalt, which maintains the steep walls of the gorge, is a comparatively thin sheet resting on unconsolidated sand and gravel, cut by basalt dikes representing the vents through which the material of the sheet was extruded. Judging from surface indications, there is little prospect of finding solid rock sufficiently near the surface to be useful as a foundation for a dam, and the loose gravels would probably allow serious loss of impounded waters by leakage.

SAN FELIPE RESERVOIR.

Little can be added to the published description[a] of this gorge as a reservoir site. The proposed dam would be 2,350 feet long and would submerge only 1,511 acres. San Felipe gorge is similar to that at San Acacia in being formed by flows of basalt capping unconsolidated sands and gravels. At this point there are two flows of basalt separated by a few feet of sand, as shown in the cross section of White

[a] Newell, F. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 275–276.

Rock Canyon, given in fig. 2. The material to an unknown depth beneath the lava sheet is sand and gravel, rendering the gorge undesirable as a dam site.

ESPANOLA RESERVOIR.

The Espanola dam site, located at the head of White Rock Canyon, has been described[a] as consisting of clay beds in which blocks of basalt are embedded, the unconsolidated material extending indefinitely beneath the bed of the river. Near this site thick beds of rhyolite tuff, west of the river, and basalt, to the east, rest on the detrital beds, as shown in the section forming fig. 2 and in Pl. IV, *B*. The absence

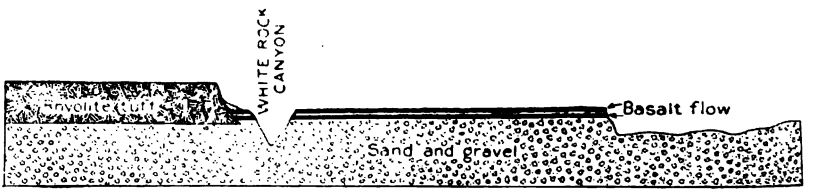

FIG. 2.—Section across White Rock Canyon near Espanola dam site.

of bed rock near the surface makes this locality of doubtful value as a dam site.

The proposed reservoir covers 5,437 acres and has a capacity of 186,861 acre-feet.

WATER SUPPLY.

SURFACE WATERS.

RAINFALL.

On account of the great differences in altitude of places that lie within short distances of one another in the Rio Grande region the amount of rainfall varies greatly from place to place, the mountain peaks serving as foci about which local storms gather. Few storms occur in which precipitation is uniform over a large area. The greater part of the rain falls as local showers close to the hills in which they originate. This fact is indicated quantitatively in the following table of rainfall, in which the stations nearest the hills show the greatest precipitation. At Santa Fe, situated at the base of the Rocky Mountains, the average yearly precipitation is 14.56 inches, while at San Marcial, situated near the center of the Rio Grande region and far from high mountains, the average is 4.84 inches and the minimum is only 1.17 inches.

[a] Newell, F. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 265-269.

TABLE 1.—*Rainfall in the Rio Grande region, New Mexico, in inches.*

Locality.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	Average for the years recorded.
Albuquerque	7.02	9.74	6.39	(7.45)	5.90	10.19	4.94	5.83	6.82	4.20	6.85
Bernalillo	7.89	11.49	5.82	6.89	4.89	.....	.....	.....	.....	.....	7.39
Cambray	.....	.....	.....	.....	.....	7.71	6.64	8.02	11.46	.....	5.96
El Paso	9.79	12.41	6.16	7.30	7.95	8.68	10.15	16.63	11.30	17.80	10.82
Engle	10.84	16.89	14.38	7.72	6.03	8.49	.....	.....	.....	.....	10.72
Espancia	8.08	.....	7.78	6.25	10.20	.....	.....	.....	.....	.....	8.08
Galisteo	12.22	.....	9.30	(11.59)	.....	16.49	.....	.....	.....	.....	12.30
Hillsboro	12.21	17.13	10.54	4.60	6.43	.....	.....	.....	.....	.....	10.18
Los Lunas	7.65	.....	.....	.....	6.05	.....	.....	.....	10.45	.....	8.71
Mesilla Park	7.99	8.96	11.21	9.67	8.40	11.96	10.90	10.29	10.13	17.09	10.65
Rincon	.....	11.74	11.13	.....	.....	.....	.....	.....	.....	.....	11.44
San Marcial	6.55	.....	.....	6.78	.....	1.17	.....	.....	.....	.....	4.84
Santa Fe	14.28	20.40	12.97	10.15	15.89	17.41	13.36	9.79	14.19	17.22	14.56
Socorro	.....	10.61	.....	7.71	7.05	10.00	.....	.....	.....	22.40	11.57
General average for the Rio Grande region											9.57

EVAPORATION.

Evaporation throughout the Rio Grande Valley greatly exceeds the rainfall. Records for only three years are obtainable, but these were made near the extremities of the region here considered, and probably represent adequately the evaporation for the entire area. The first was made at the International dam site near El Paso during the year 1890.[a] Those for the years 1900 and 1903 were made at the Climatological Laboratory of the University of New Mexico at Albuquerque.[b]

TABLE 2.—*Evaporation in the Rio Grande region, in inches.*

	At International reservoir site for 1890.	At Albuquerque for 1900.	At Albuquerque for 1903.		At International reservoir site for 1890.	At Albuquerque for 1900.	At Albuquerque for 1903.
January	2.0	2.04	1.81	August	11.4	10.21	11.73
February	2.0	2.63	2.07	September	9.2	8.00	9.65
March	7.0	6.17	5.21	October	6.8	4.38	6.62
April	7.3	6.82	10.05	November	4.6	1.73	4.21
May	10.8	10.08	10.98	December	2.9	1.40	1.88
June	11.2	12.63	11.33				
July	9.6	11.78	12.36	Total	84.8	77.87	87.90

Average for three years, 83.5.

DRAINAGE.

The drainage area of the Rio Grande north of El Paso, according to the reports of stream measurements made by the United States Geological Survey, is 38,000 square miles, of which 7,695 square miles lie north of Cenicero, Colo., leaving about 30,000 square miles as the area of the drainage basin within New Mexico.

The Rio Grande is mainly a flood-water stream and is subject to great fluctuations in volume. Its permanent flow is slight and is

[a] Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1890-91, p. 411.

[b] Weinzirl, John, Bull. Hadley Climatological Laboratory, Univ. New Mexico, vol. 11, No. 10, 1905, pp. 5-8.

derived mainly from the mountains north and east of the area described. The tributaries within the Rio Grande region yield little permanent supply, although Galisteo Creek and Rio Puerco contribute small volumes of water during the greater part of the year. Many of the tributary channels carry small permanent streams near their heads in the hills, but the water in most of these sinks beneath the surface before reaching the river.

The floods that supply the greater part of the flow of the Rio Grande are of two general kinds, one due to the annual melting of snows in the mountains, often accompanied by general rain storms, the other due to local showers or "cloud-bursts." The first occur regularly, but those due to local showers are very irregular, both in volume and in time of occurrence. Sometimes the river bed is dry for several months and at other times it carries disastrous floods, the yearly discharge, for example, at El Paso, varying from 50,768 to 2,011,794 acre-feet, or a proportion approximating 1:40.

The records of discharge kept by the Geological Survey since 1897 at El Paso, San Marcial, and Ildefonso, and since 1899 at Cenicero, near the Colorado and New Mexico boundary, are as follows:

TABLE 3. *Monthly discharge of the Rio Grande, in acre-feet.*

EL PASO, TEX.

Month.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	18,754	30,129	12,912	8,110	278	8,291	615	972	35,920
February	10,774	33,655	11,330	5,680	4,502	5,772	1,289	387	43,309
March	4,127	20,044	7,071	160	3,669	635	22,602	0	188,489
April	103,537	97,944	8,807	300	0	7,904	49,468	0	197,911
May	511,088	140,192	10,330	14,810	158,102	526	203,623	0	545,980
June	562,677	111,570	0	93,100	77,038	307	586,909	0	851,147
July	81,770	196,269	19,553	70	12,576	20	158,202	0	58,800
August	8,116	31,236	430	0	60,655	14,499	4,334	7,398	19,785
September	11,950	2,262	0	16,483	21,005	9,313	1,031	10,959	3,322
October	108,096	160	123	0	5,336	1,428	2,033	366,486	4,225
November	67,359	119	119	0	12,813	298	298	48,397	25,458
December	11,812	5,718	2,828	738	7,993	1,775	2,440	38,182	37,478
Year	1,360,300	669,298	73,503	169,751	363,967	50,768	1,032,844	472,781	2,011,794

Total for nine years, 6,205,006; average for nine years, 689,452.

SAN MARCIAL, N. MEX.

Month.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	19,553	57,675	27,854	10,582	24,718	22,731	17,197	16,840	39,114
February	24,325	59,425	24,603	35,099	25,468	17,135	21,927	18,902	63,868
March	40,767	62,164	27,546	33,203	15,114	7,954	46,790	6,060	217,904
April	212,548	271,458	54,089	6,248	23,683	40,106	100,007	0	279,392
May	755,196	165,832	35,048	123,590	256,126	26,787	318,367	0	962,221
June	366,426	126,268	952	159,888	96,178	6,407	660,476	0	714,268
July	65,977	167,062	28,407	123	59,286	0	77,841	10,532	35,782
August	6,149	13,835	6,395	0	65,534	49,210	3,064	55,974	20,093
September	114,188	4,641	2,916	73,190	37,607	13,349	1,438	44,727	5,276
October	281,677	1,230	676	123	17,018	823	545	463,240	7,349
November	175,715	11,722	9,521	2,440	20,053	4,641	5,534	51,769	42,397
December	152,736	23,365	21,828	10,084	19,240	11,286	18,883	41,752	34,344
Year	2,215,257	964,677	239,835	484,570	660,025	200,729	1,272,069	709,796	2,422,008

Total for nine years, 9,168,966; average for nine years 1,018,774.

ABLE 3.—*Monthly discharge of the Rio Grande, in acre-feet*—Continued.

ILDEFONSO, N. MEX.

	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
.....	28,715	21,705	26,009	36,770	24,410	29,643	23,127	20,910	43,470
.....	30,101	24,936	35,599	32,322	36,543	27,183	24,724	24,220	51,590
.....	60,750	33,449	81,164	52,818	45,624	33,709	75,193	21,340	158,100
.....	303,113	265,864	176,430	51,531	83,425	97,577	172,324	27,310	218,900
.....	702,254	200,328	117,687	211,517	319,367	73,567	406,612	24,160	785,200
.....	366,128	223,973	23,742	173,395	130,850	28,215	709,468	17,020	572,700
.....	97,274	161,590	36,647	18,262	44,824	16,730	136,780	15,130	53,740
.....	27,423	39,168	22,197	10,145	50,850	34,165	26,563	91,990	38,680
.....	40,463	19,279	53,137	42,605	34,512	28,790	22,314	148,300	23,150
.....	136,196	21,890	26,563	23,796	30,190	17,157	21,828	252,800	25,950
.....	71,881	35,583	44,985	25,289	27,491	18,386	25,170	49,450	37,960
.....	32,220	39,168	38,184	29,022	28,468	19,220	23,611	35,420	37,940
.....	1,896,518	1,086,933	682,344	707,472	856,554	424,342	1,667,714	728,050	2,047,380

line years, 10,097,307; average for eight years, 1,121,923.

CENICERO, COLO.

Month.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
.....	(a)	39,229	36,524	32,035	1,537	18,820	59,640
.....	(a)	42,153	32,267	42,097	1,388	23,990	66,370
.....	(a)	35,847	22,443	33,757	2,091	7,563	53,490
.....	(a)	20,826	16,542	18,744	18,684	9,104	44,270
.....	(a)	87,927	103,299	30,129	123,713	1,322	390,300
.....	(a)	84,734	61,408	6,783	379,339	1,208	507,600
.....	2,582	1,783	5,041	1,353	72,432	1,076	15,860
.....	3,259	1,353	3,689	1,045	2,890	8,608	9,469
.....	6,069	1,845	2,975	1,547	5,355	11,660	3,725
.....	7,194	2,275	3,320	1,968	3,035	97,770	6,044
.....	15,412	9,223	4,284	1,785	12,674	24,750	12,850
.....	19,553	35,109	20,721	2,275	18,569	53,310	31,730
.....	.....	362,304	312,513	173,518	642,607	259,181	1,210,000

a No record.

six years, complete, 2,960,123; average for six years, 493,354.

UNDERGROUND WATERS.

io Grande region embraces several more or less separate geo-ovinces and the underground-water resources may be most ntly described by districts.

SANTA FE DISTRICT.

anta Fe district is located in the Rocky Mountains region on Grande north of Galisteo Creek. The strata, composed of consolidated sands, gravels, and beds of mountain wash of age, dip to the west away from the mountains. The incli-f the strata and their exposure in the region of greatest pre-n within the area described are favorable to the occurrence an water.

two deep wells have been sunk in these deposits, and in neither was water found under notable pressure. The first one, everal years ago in search of artesian water, is 8 miles south a Fe. In this no surface flow was obtained. The second,

drilled in 1905 at the Santa Fe Indian School, is a 12-inch well, 989 feet deep, and penetrates angular wash principally except for 75 feet of conglomerate encountered at a depth of 225 feet. Water was found at a depth of 100 feet and rose 44 feet, but its volume is small and the supply is easily exhausted by pumping. Water was also obtained in the 75 feet of conglomerate and in several thin gravel strata not recorded. This well is on comparatively high ground, its altitude being about 7,000 feet, and near the eastern or highest part of the detrital formation. It is probable that on lower ground, nearer the river, water might be found under pressure sufficient to produce surface flows. Water emerges from this formation as springs along the river at an altitude about 1,500 feet lower than that at Santa Fe and along the lower reaches of Santa Fe Creek. At La Cienaga, 12 miles southwest of Santa Fe and about 700 feet lower, there are several springs of sufficient volume to irrigate a considerable tract of land.

Record of well at Santa Fe Indian School.

	Feet.
Mountain wash	0–225
Conglomerate	225–300
Mountain wash	300–989

ALBUQUERQUE DISTRICT.

The Albuquerque district may be considered as extending from Galisteo Creek southward to Isleta. The geologic formations, so far as they have been penetrated by wells, are composed of unconsolidated material and carry no water under pressure. Water saturates the flood-plain material to the level of the river and is found in abundance wherever wells penetrate to that level.

A few wells sunk on the "mesa" east of Albuquerque obtain water at horizons somewhat higher than that of the river. A well at the University of New Mexico,[a] 1 mile east of Albuquerque, is 240 feet deep and contains water at a depth of 200 feet, about 20 feet higher than the river level, while the "military well," 7 miles east of Albuquerque, contains water at a depth of 420 feet, or about 130 feet above the river level.

The deepest well in this district, 710 feet, is in Albuquerque, at the city waterworks. It is a 12-inch double-steel-cased well, to which water is admitted only below a depth of 350 feet. In addition to this deep well the water company owns seven 6-inch wells and one 12-inch well, each 291 feet deep, and a 65-foot dug well, from the bottom of which 25 pipes are driven to depths of 35 feet, the water being admitted only from the bottom of these pipes, or 100 feet below the surface.

[a] Weinzirl, John, Bull. Hadley Climatological Laboratory of University of New Mexico, vol. 10, 1905, p. 12.

he wells together yield an average of 3,000,000 gallons a day, or 3 gallons a minute.

he 710-foot well has been tested alone and yielded 600 gallons a ute, with a local depression of the water surface within the well of eet.

Record of the city waterworks well at Albuquerque, N. Mex.

	Feet.
Soil	0– 10
Sand and coarse gravel	10– 35
Clay	35– 40
Sand and coarse gravel	40– 71
Cemented sand	71– 75
Clay	75– 80
Cemented sand and bands of "sandstone"	80–179
Sand and gravel	179–185
Clay	185–189
Cemented sand and clay	189–243
Yellow clay	243–292
Cemented sand	292–320
Yellow clay	320–362
Sand and clay	362–386
Shale and sand	386–397
Cemented sand	397–442
Yellow clay	442–456
Cemented sand	456–471
Sand and clay	471–487
Clay, sand, and gravel	487–572
Quicksand	572–614
Clay and cemented sand	614–710

BELEN DISTRICT.

GENERAL CONDITIONS.

he Belen district extends from Isleta southward to a point a few s north of Socorro, where the Rio Grande Valley narrows between encroaching hills, as shown in Pl. I. Through the center of this ict extends the erosion basin known as Belen Valley. The surface ie broad flood plain formed by the deposits flooring the valley ds only a few feet above the river bed, and the material composing deposits is saturated with water. Shallow wells throughout the om land reach this water at depths of 5 to 15 feet and readily in it in large quantity.

WELLS.

ie Atchison, Topeka and Santa Fe Railway Company's well, 1.5 s south of Belen, is the only one within this district from which a and constant supply is pumped. It is a dug well, 15 feet deep 20 feet in diameter, and contains 7 feet of water. It has yielded

50,000 gallons a day, and would probably yield more if nece
The well is situated on the flood plain of the river in gravel and c
sand, and the water level in the well rises and falls with that of
river.

No important deep wells have been sunk on the lowlands of
Belen district. One at the Belen flour mill, 35 feet deep, owned
John Becker, and another at the Catholic Church, 85 feet deep,
the deepest.

Three deep wells have been bored in the mesa gravels. One at
orado siding, on the Atchison, Topeka and Santa Fe Railway bra
known as the Belen cut-off, is 500 feet deep and contains 34 fe
water. This well is 9 miles southeast of Belen (altitude, 4,788 f
at an elevation of 5,012 feet, or 224 feet higher than Belen, the w
level in this well being 234 feet lower than the water at Belen.

Record of Atchison, Topeka and Santa Fe Railway Company's well at Colorado siding, Mexico.

	Feet.
Soil	1–24
Sand	24–290
Light-colored clay	290–340
Red sandy clay	340–500

At Becker siding, 15 miles southeast of Belen, the railway comp
has a 6-inch bored well, 427 feet deep, with water standing 364
below the surface. The altitude at the well is 5,140 feet, or 352
above Belen, making the water level in the well 4 feet lower than t
in the valley at Belen.

Record of Atchison, Topeka and Santa Fe Railway Company's well at Becker siding, Mexico.

	Feet.
Cemented gravel	0–100
Red clay	100–150
Red clay and gravel	150–275
Red clay	275–290
Red clay and gravel	290–300
Red clay and gravel, with bowlders	300–340
Gravel	340–345
Red clay and gravel, with bowlders	345–378
Gravel	378–388
Red clay and gravel	388–400
Water bearing gravel	400–420
Gravel and clay	420–427

At Sandia, a siding on the main line of the Atchison, Topeka
Santa Fe Railway, west of Isleta, the railway company bored a
inch well 893 feet deep during the summer of 1905. It is in s
gravel, and clay throughout, and encountered water at a dept
445 feet.

of Atchison, Topeka and Santa Fe Railway Company's well at Sandia, N. Mex.

	Feet.
Unconsolidated sand	0–340
Sand, with clay bands	340–400
Clay	400–440
Sand	440–480
Gravel	480–490
Sand, with clay bands	490–530
Sand	530–585
Clay	585–640
Sand and clay	640–893

JORNADA DISTRICT.

GEOLOGIC STRUCTURE.

he Jornada district extends from San Marcial to Las Cruces, veen the San Andreas and the Caballos-Fra Cristobal mountain ges. The geologic structure of the Jornada del Muerto has been ribed[a] as a syncline, in which the older or consolidated rocks pass erneath the unconsolidated material which covers the surface.

long the eastern base of the Caballos-Fra Cristobal range the rned Cretaceous sandstones are truncated and exposed in such a as to freely admit the water crossing them as streams from the ntains, as well as that falling upon them as rain. These sand- es are not exposed elsewhere within the Jornada district, and it is rtain whether they occupy the entire trough of the syncline, as d by Keyes.[b]

ie Jornada del Muerto, as has been previously stated, is probably rt of the old Rio Grande Valley that has been filled with uncon- ated sands and gravels of comparatively recent origin. This rial has been penetrated by wells to a depth of 360 feet, but its depth has not been determined and very little is yet known of underground conditions in this region. The Cretaceous sand- s may extend without interruption beneath the detrital filling, f they were originally present, may have been largely eroded previous to the deposition of the detritus.

FLOWING WELLS.

the vicinity of Engle flowing water is obtained from three wells, h penetrate the Cretaceous sandstones. One about 10 miles rwest of Engle, near the base of the Fra Cristobal Mountains, is to be 260 feet deep. The flow is not sufficient to water a few lred cattle for which it is used, and the water is pumped to ase the yield.

[a] Keyes, C. R., Water-Sup. and Irr. Paper No. 123, U. S. Geol. Survey, 1905.
[b] Ibid., p. 10 (geologic map).

The other wells belong to the Santa Fe Railway Company and t water is pumped to Engle for railway use. The wells are located the canyon leading from Engle to the Rio Grande. One near Fort McRae was drilled to a depth of about 1,200 feet in search coal. No coal was found, but water was encountered under pressu sufficient to produce a considerable surface flow but not great enou to raise it to the level of the town. From this well and a second o put down about 2 miles farther east water is pumped into a reserv on the Jornada, from which it flows to Engle by gravity.

NONFLOWING WELLS.

A number of wells have been bored in the Jornada del Muerto, b definite records of only a few of them are obtainable. Those near t western border of the plain, along the railroad, penetrate the Cret ceous sandstones and find water under slight pressure, but the great number have been bored in depressions along the center of the pla and penetrate only unconsolidated sand, gravel, and wash. T record of Mr. Linger's well may be taken as representative of t material found in the center of the Jornada.

Record of well of G. W. Linger & Company, 5 miles east of Upham.

	Feet.
Red clay	1–10
Cement	10–19
Sand and silt	19–235
Bowlders (maximum diameter, 8 inches)	235–240

Partial records obtained of a few of the wells are given in the f lowing table:

TABLE 4.—*Records of bored wells in the Jornada del Muerto.*

Owner.	Location.	Total depth	Depth to water.	Power used.	Remarks.
		Feet	*Feet*		
J. D. Isaacks	Sec. 35, T. 20 S., R. 2 E.	265	250	Wind	Penetrates 35 feet s 23 feet sand gravel
Do	Sec. 25, T. 21 S., R. 2 E.	330	292	Gasoline	In sand and gravel
Do	Sec. 13, T. 20 S., R. 2 E.	115	95	Wind	
J. W. Taylor	Sec. 17, T. 19 S., R. 2 E.	360	345	do	Penetrates 345 feet gular material, v 15 feet rounded bo ders
A., T. and S. F. Rwy	8 miles west of Engle	1,200	Flow.	Gasoline	In sandstone shale.
Do	2 miles south of Upham	480	140	Steam	
Do	1 mile west of Ataman	400	No water		
L. Baldwin & Co	Ataman	140	140	Steam	Water raised 100
Victoria Land and Cattle Co	4 miles north of Engle	200			In red sandstone.
Do	10 miles north of Engle	500	492	Gasoline	Water raised 327
G. W. Linger & Co.	5 miles northeast of Upham.	240	236	do	Sand and gra (maximum 6 in in diameter) at tom. Water ra 102 feet
Mr. Turner	18 miles east of Rincon	350	300(?)	do	In sand and grave

INDICATIONS OF ARTESIAN WATER.

The occurrence of water under pressure in several wells near Engle indicates the presence of artesian conditions beneath a small area of the Jornada, but in areas lying beyond the immediate vicinity of Engle the presence or absence of artesian water must be inferred entirely from surface indications. Since water is found in the Cretaceous sandstones near Engle it might be expected in wells that penetrate these sandstones elsewhere, provided the sandstones extend uninterruptedly beneath the surface in this region. Their extent, however, and their depth beneath the surface over the greater part of the Jornada are unknown.

The water in the unconsolidated gravel beds may perhaps be confined beneath impervious layers, since the Jornada del Muerto slopes southward at an average rate of 4½ feet to the mile, but nothing now known proves either the presence or absence of such layers. The surface indications are moderately favorable to the occurrence of artesian water in certain areas, particularly at the southern end of the Jornada and still farther south, in the Mesilla Valley.

LA MESA DISTRICT.

La Mesa district lies in the southern part of the Rio Grande region west of Mesilla Valley. Wells have been sunk in various parts of this district, both for railroad use and for stock purposes. No solid rock was encountered in any of the wells, most of which find water in abundance, but at a considerable depth, as indicated in Table 5. The deepest well on La Mesa, 945 feet, was bored by the Southern Pacific Railway Company at Lanark. The company owns two other wells at the same place, one 648 feet and one 615 feet deep, the three yielding 50 gallons of water a minute. The material penetrated is sand with small waterworn pebbles, and contains water below a depth of 380 feet.

Since the altitude of Lanark is 4,156 feet, the altitude of the water surface is 3,776 feet, while that at Bosque Seco, in Mesilla Valley, 15 miles northeast of Lanark, is 3,800 feet—24 feet higher than at Lanark. At Noria, the altitude of which is 4,114 feet, the water surface, 358 feet below the surface of the land, is 3,756 feet above sea level. In the 12 miles between Lanark and Noria the water surface inclines to the south 20 feet, or at an average rate of 1.7 feet per mile. A line drawn through Bosque Seco, Lanark, and Noria would run somewhat west of the center of the old débris-filled valley of the Rio Grande for a distance of 27 miles. Along this line there is a fall of the water surface of 44 feet, or an average of 1.7 feet per mile. The gradient of the water table in Mesilla Valley between Bosque Seco (3,800 feet) and the southern end of

Mesilla Valley (3,680 feet), a distance of about 32 miles, is 3.7 fe per mile. It is evident from these facts that the surface of th underground water has a regular gradient down the old channe through La Mesa, although it is less than the gradient of the river. line of wells a few miles farther east in the center of the old valle would probably show a steeper gradient of the water plane.

The facts upon which the determination of gradient rests are no sufficiently numerous to make it conclusive. The depths to wate determined and the indications that La Mesa is a part of the ancient débris-filled valley naturally leads to the inference that the course of the underflow should be southward through the detritus of La Mesa. It is possible, on the one hand, that additional data will show a gradient steeper than 1.7 feet per mile. On the other hand, it is possible that the original course of the underflow down the old channel has been reversed by reason of the down cutting of the river in Mesilla Valley and the accumulation of surface water in the gravels of La Mesa. The latter possibility is strengthened by the facts that La Mesa is nearly level and the material so porous that rain enters it without producing even temporary streams.

TABLE 5.—*Records of bored wells in La Mesa district.*

Owner.	Location.	Total depth.	Depth to water.	Power used.	Material encountered
		Feet.	*Feet.*		
Henry Brock	Sec. 30, T. 25 S., R. 2 W.	240	221	Gasoline	Sand and waterwor gravels.
Do	Sec. 7, T. 24 S., R. 1 W.	430	386	do	Do.
Do	T. 24	515			Clay.
Mr. Hawkins	5 miles west of Picacho Mountain.	218	170	Gasoline	
Robert Herrington	2 miles northwest of Noria.	435	350	do	Sand and gravel.
J. F. Kilburn	T. 27 S., R. 1 W.	[a] 478	408		Do.
Do	6 miles northwest of Lanark.	388	370	Gasoline	Sand and waterwor gravel.
S. P. Rwy. Co.	Lanark	945	380	Steam	Do.
Lewis Bros.	5 miles northeast of Lanark.	365	340	Gasoline	Sand and gravel.
J. B. Stahling	10 miles west of Lanark.	[b] 460	440		
Do	6 miles west of Lanark.	350	311	Gasoline	
El Paso and S. W. Rwy.	Potrillo	240	220	do	Sand and clay.
Do	Noria	438	358	do	Sand and gravel.

[a] 170 feet in bottom of crater. [b] 200 feet in bottom of crater.

MESILLA DISTRICT.

LOCATION AND CHARACTER.

The Mesilla district is confined to Mesilla Valley, the southernmo of the erosion basins of the Rio Grande region. During floods tl river submerges a large part of the valley floor, a level flood pla formed by the deposition of silt and fine sand. As previously stat (p. 24), Mesilla Valley was once deeper than it is now, and has be recently filled to some extent by flood-plain deposits. The geolog

formations and their relation to one another are indicated in the sections on Pl. III. The rock basin was partly filled with débris, in which a secondary valley was eroded and later partly filled with sand and silt.

WATER TABLE.

Underground water is found throughout Mesilla Valley at practically the river level. The depth to water was measured in the wells in the valley, and the results were plotted on the contour maps prepared by the United States Reclamation Service, and from these the map forming Pl. X has been prepared, which shows by contours the depth to water.

The water table changes position to some extent, according to changes in the volume of water in the river. Professor Slichter[a] has shown that the ground water of the valley is derived largely from the river and that the gradient of the water plane in a direction parallel to the river is practically constant at 4.64 feet per mile where measured near Mesilla Park, while the gradient away from the river varies from 0.4 foot per mile during low water to 2.3 feet in times of flood. A rise of the water table of 5 feet is reported near the river during the six months for which records were kept.

WELLS OF MESILLA VALLEY.

General statements.—A number of wells have been bored in Mesilla Valley for pumping water in large quantities, mainly for irrigation. Twelve of these have been carefully tested by Professor Slichter[b] with a view to ascertaining their capacity, the cost of pumping, etc. Some of his results are included in Table 6 (p. 47). It should be noted, in comparing the figures of the column showing depth to water with the map (Pl. X), in which depth to water is indicated by contours, that these wells are usually placed on ground high enough to allow the water to flow over the land to be irrigated. The depth to water is therefore somewhat greater than the average depth indicated on the map.

Wells at Agricultural College.—Several wells have been bored for the Agricultural College at Mesilla Park.

A bored well at the college building is 75 feet deep and 4 inches in diameter. Water was encountered at a depth of 43 feet in 1896, but in 1903 it was found to have lowered to 53 feet.

Another 4-inch well at the college machine shop is 120 feet deep. Saline water was found at this depth and the pipe was drawn back to 75 feet, where better water was found.

An irrigation plant was established in 1902 at the experiment station of the Agricultural College, consisting of one 12-inch and one

[a] Slichter, C. S., Observations on the ground waters of Rio Grande Valley. Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 22-29.

[b] Slichter, C. S., Ibid., p. 34.

6-inch well, each 48 feet deep. This plant has been described by members of the college faculty[a] in a bulletin of the experiment station. The wells penetrate gravel beds, from which water is readily obtained, the yield being about 1,000 gallons a minute.

Record of experiment station well.

	Feet.
Soil	0– 5
Sand	5–32
Sand and gravel	32–47
Sand	47–48

During the summer of 1905 a pumping plant was installed on the horticultural farm near Mesilla Park station. A 12-inch well was bored 62 feet deep and an 18-foot strainer was placed at the bottom. A pit 8 feet square was dug to water level, 19 feet below the surface. It contains a centrifugal pump with gasoline engine, which discharges 1,000 gallons of water per minute.

Wells of F. C. Barker.—Mr. Barker has three pumping plants. One, at Las Cruces, pumps from a 6-inch well 53 feet deep, which is capable of supplying about 150 gallons of water per minute. The well penetrates a gravel bed 35 feet thick, which supplies the water.

Record of F. C. Barker's well at Las Cruces

	Feet.
Soil	0– 3
Sand	3–18
Gravel and bowlders	18–53

Mr. Barker's second pumping plant is situated about 1 mile south of Las Cruces and consists of a 6-inch well 48 feet deep, supplied with pump and gasoline engine which raise 131 gallons of water per minute.

Record of F. C. Barker's well, 1 mile south of Las Cruces.

	Feet.
Soil	0– 8
Sand	8–16
Sand and gravel	16–30
Coarse gravel	30–48

A third plant is reported to have been established during the summer of 1905 near the second. An 8-inch well was bored to a depth of 85 feet and supplied with centrifugal pump and gasoline engine, which raise a volume of water estimated at 800 gallons per minute.

Record of F. C. Barker's 8-inch well.

	Feet.
Soil	0–17
Quicksand	17–36
Sand and gravel	36–58
Gravel and bowlders	58–75
Caliche	75–79
Sand and gravel	79–85

[a] Vernon, John J., and Lester, Francis E., Bull. No. 45, New Mexico College Agric. and Mechanic Arts, Mesilla Park, N. Mex., 1903.

Well of Mrs. E. M. Boyer.—Mrs. Boyer's well is located on her ranch, about one-fourth mile north of the railroad station at Las Cruces. It is a 6-inch bored well, 52 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 658 gallons per minute.

Record of Mrs. E. M. Boyer's well.

	Feet.
Soil	0– 2
Sand	2–22
Sand and gravel	22–52

Well of Frank Burke.—Mr. Burke's well is located one-half mile south of Mesilla Park. It is a 12-inch well, 60 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 21-horsepower gasoline engine at the rate of 755 gallons per minute.

Record of Frank Burke's well.

	Feet.
Soil	0– 8
Sand	8–22
Sand and gravel	22–60

Well of J. C. Carrera.—Mr. Carrera's well is located about 1 mile south of Las Cruces. It is a 6-inch well, 58 feet deep, with a 15-foot strainer. Water is raised by a centrifugal pump and 8-horsepower gasoline engine at the rate of 648 gallons per minute.

Well of Robert Elwood.—Mr. Elwood, of Las Cruces, constructed a pumping plant for irrigation during the summer of 1905, in which two 8-inch wells 40 feet apart are connected with a 5-inch centrifugal pump and 12-horsepower gasoline engine. The first well was bored 100 feet deep, but the casing was later withdrawn to the 64-foot level, where the most productive gravel bed occurs. The second well is 64 feet deep, and both are supplied with 24-foot strainers. The yield is estimated at 800 gallons of water per minute.

Record of Robert Elwood's well.

	Feet.
Sand and gravel	0– 32
Clay	32– 35
Sand and gravel	35– 50
Cemented sand	50– 52
Coarse sand and gravel	52–100

Well of W. N. Hager.—Mr. Hager's well is located one-half mile west of Mesilla Park. It is a 10-inch well, 63 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 325 gallons per minute.

Well of A. L. Hines.—Mr Hines's well is located 1 mile northeast of Mesilla. It is a 6-inch well, 59 feet deep, with an 8-foot strainer.

Water is raised by a centrifugal pump and 8-horsepower gasoli engine at the rate of 271 gallons per minute.

Record of A. L. Hines's well.

	Feet.
Soil	0– 8
Sand	8–19
Quicksand	19–47
Sand and gravel	47–59

Wells of Horaco Ranch Company.—The Horaco Ranch Company ha three wells separated by a few hundred feet and located west of Berino

No. 1 is an 8-inch well, 75 feet deep, with an 18-foot strainer. Wate is raised by a centrifugal pump and 12-horsepower gasoline engine a the rate of 837 gallons per minute.

No. 2 is a 10-inch well, 53 feet deep, with an 18-foot strainer. Wate is raised by a centrifugal pump and 12-horsepower gasoline engine a the rate of 191 gallons per minute.

No. 3 is a 10-inch well, 62 feet deep, with an 18-foot strainer. Wate is raised by a centrifugal pump and 12-horsepower gasoline engine a the rate of 750 gallons per minute.

Las Cruces city well.—During the summer of 1905 a pumping plan was constructed to furnish the city of Las Cruces with water. A 6-inch well was bored to a depth of 63 feet and an 18-foot straine placed at the bottom of the pipe in a bed of gravel, occurring belo the depth of 46 feet. A pit 8 feet square and 20 feet deep contains a Advance steam pump, which is placed 2 feet above normal wate level. The water is drawn by suction from the capped casing at rate of 300 gallons per minute.

The water drawn from a depth lower than 46 feet is apparentl much better for domestic use than that obtained from the surfac wells of Las Cruces. An analysis of the water made by Geo. W. Lor Company, of Philadelphia, Pa., is as follows:

Analysis of water from Las Cruces city well.

	Parts per million.		Parts per millio
Total solids	998	Chlorine (Cl)	1
Calcium (Ca)	156	Silica (SiO_2)	
Magnesium (Mg)	19	Carbonate radicle (CO_3)	1
Sodium (Na)	159	Organic and volatile	Tra
Sulfate radicle (SO_4)	338		

Well of Theodore Roualt.—Mr. Roualt's well is located on his ran near the river, 3 miles northwest of Las Cruces. It is a 10-inch we 48 feet deep, with a 10-foot strainer. Water is raised by a centrifug pump and 18-horsepower steam engine at the rate of 351 gallons p minute.

Well of Shalam Colony.—Several years ago an elaborate pumping plant was constructed for irrigation purposes at Shalam Colony, west of Dona Ana. A circular pit 18 feet in diameter was sunk to a depth of 30 feet and its sides and bottom were cemented. In the bottom of this pit five wells were bored, three of which are 6 inches in diameter and 90 feet deep (60 feet below the bottom of the pit), one is 12 inches in diameter and 90 feet deep, and one 6 inches in diameter and 197 feet deep. At a depth of 90 feet there is a 3-foot gravel stratum, which apparently yields the greater part of the water. The sand beneath this stratum entered the pipe so freely that it was impracticable to draw water from horizons lower than 90 feet.

A storage reservoir, covering an area of 1 acre and 5 feet deep, was constructed, and into this a 60-horsepower steam engine pumps water at the rate of 1,500 gallons per minute.

The ground water at this place is 9 feet beneath the surface, making a normal depth of 21 feet of water in the pit. The pump lowers the water surface 18 feet to a level at which it remains stationary, the flow from the wells equaling the discharge of the pump.

Well of J. R. Thompson.—Mr. Thompson's well is situated at the eastern edge of the valley, about 2 miles south of Earlham. It is a 6-inch bored well, 138 feet deep, and obtains water from the coarse sand at the bottom of the well. An accurate driller's record was obtained as follows:

Record of J. R. Thompson's well.

	Feet.
Sand and silt	0– 80
Clay	80–100
Sand	100–118
Clay	118–128
Coarse sand	128–138

Well of G. H. Totten.—Mr. Totten's well is located 1 mile west of Mesilla. It is a 10-inch well, 62 feet deep, with 24 feet of strainer. Water is raised by a centrifugal pump and 28-horsepower gasoline engine at the rate of 464 gallons per minute. When tested the well contained only 12 feet of strainer, which had been placed in the upper sand layer. Later the well was lowered and a second 12-foot strainer was added, greatly increasing the flow.

Record of G. H. Totten's well.

	Feet.
Soil	0–17
Sand	17–51
Clay	51–53
Sand and gravel	53–62

Samples of the waters were taken from both sand layers of this well to ascertain if they varied in quality. The analyses, made by Prof.

R. F. Hare, of the New Mexico agricultural experiment station, indicate that the waters vary in the amounts, but not in the kinds of salts they contain, that from the upper sand containing 1,566 parts and that from the lower sand 1,123 parts of total solids per million parts of water.

Table showing well records in Mesilla Valley.—The following table comprizes data concerning wells in Mesilla Valley. Descriptions of pumping tests for the first twelve wells of the table may be found in Prof. Charles S. Slichter's paper on ground waters of Rio Grande Valley:[a]

[a] Water Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 51–73.

TABLE 6.—*Records of wells in Mesilla Valley.*

	Owner.	Location.	Total depth.	Depth to water.	Yield per minute.	Water lowered by pumping.	Specific capacity per minute.	Specific capacity per square foot of strainer per minute.	Size of well.	Power used.	Use.	Cost of water per acre-foot.	Total lift in feet.
			Feet.	*Feet.*	*Gals.*	*Feet.*	*Gals.*	*Gals.*	*In.*				
1	F. C. Barker	1 mile south of Las Cruces	48	14	131	22.48	5.83	0.337	6	Gasoline	Irrigation	$13.20	45.58
2	Mrs. E. M. Boyer	Las Cruces	52	20	658	19.76	33.30	1.969	6	do	do	3.47	40.30
3	F. Burke	¼ mile south of Mesilla Park	60	14	755	22.85	31.75	.930	12	do	do	4.87	40.45
4	J. C. Carrera	2 miles north of Mesilla Park	58	.....	648	8.48	74.60	3.530	6	do	do	3.16	26.85
5	W. N. Hager	¼ mile west of Mesilla Park	63	.....	325	15.20	22.30	.760	10	do	do	9.57	34.77
6	A. L. Hines	1 mile northeast of Mesilla	59	20	271	14.08	19.20	1.790	6	do	do	8.95	36.05
7	T. Roualt	3 miles northwest of Las Cruces	48	.....	351	23.86	16.00	.620	10	do	do	7.91	34.16
8	G. H. Totten	¼ mile west of Mesilla	62	17	464	22.50	20.60	.760	10	do	do	8.19	43.35
9	Agricultural College	Mesilla Park	48	.....	1,000	11.37	88.00	2.320	12	Steam	do	4.70	29.55
10	Horace Ranch Co. No. 1	Berino	75	5	837	13.75	60.80	1.690	10	Gasoline	do	2.21	23.89
11	Horace Ranch Co. No. 2	do	53	8	191	23.64	8.10	.178	10	do	do	10.90	35.26
12	Horace Ranch Co. No. 3	do	62	8	750	18.55	40.40	.892	10	do	do	2.46	32.36
13	Academy Loretto	Las Cruces	66	26	300	.....	.....	.....	.....	do	Domestic	.....	.....
14	P. S. Ames	do	51	21	130	.....	.....	.....	.....	do	Irrigation	.....	.....
15	A., T. & S. F. Rwy	Earlham	25	10	40	.....	.....	.....	120	Wind	Engines	.....	.....
16	Agricultural College	Mesilla Park, west of railway	62	19	1,000	.....	.....	.....	12	Gasoline	Irrigation	.....	.....
17	F. H. Bascom & Co	Las Cruces	46	35	30	.....	.....	.....	4	do	Factory	.....	.....
18	F. C. Barker	Las Cruces, near station	53	18	150	.....	.....	.....	6	do	Irrigation	.....	.....
19	do	1 mile south of Las Cruces	85	16	800	.....	.....	.....	8	do	do	.....	.....
20	S. F. Bean	Las Cruces	64	34	35	.....	.....	.....	6	do	do	.....	.....
21	Catholic Church	do	36	34	50	.....	.....	.....	Dug	do	do	.....	.....
22	City waterworks	do	63	22	300	.....	.....	.....	6	Steam	City	.....	.....
23	R. Elwood	do	100	17	800	.....	.....	.....	8	Gasoline	Irrigation	.....	.....
24	W. S. Gilliam	Mesilla Park	52	16	800	.....	.....	.....	10	do	do	.....	.....
25	Doctor Lane	5 miles east of Fort Fillmore	260	Dry	.....	.....	.....	.....	6	.....	.....	.....	.....
26	do	6½ miles east of Fort Fillmore	330	Dry	.....	.....	.....	.....	6	.....	.....	.....	.....
27	L. Quintero	1 mile south of Las Cruces	35	20	.....	.....	.....	.....	6	Steam	Irrigation	.....	.....
28	Shalam Colony	Las Cruces	197	9	1,500	.....	.....	.....	6	do	do	.....	.....
29	S. A. Steele	1 mile south of Las Cruces	83	17	.....	.....	.....	.....	8	Gasoline	do	.....	.....
30	W. G. Stewart	2 miles north of Las Cruces	35	25	30	.....	.....	.....	2	do	do	.....	.....
31	J. B. Thompson	2 miles southeast of Earlham	138	.....	.....	.....	.....	.....	6	Windmill	Domestic	.....	.....

UNDERFLOW OF THE RIO GRANDE REGION.

WATER PLANE.

In Mesilla Valley the surface of the ground water is practically at the river level, as has been previously stated. The water plane in the valleys farther north can not be accurately represented for lack of detailed topographic maps, but the depths to water in wells situated in the bottom lands throughout the Rio Grande region indicate that the surface of the ground water is always at or very near the river level. The water plane determined for Mesilla Valley and mapped in Pl. X is probably typical, and the map doubtless expresses with sufficient accuracy the relation of the water table to the river and to the land surface for the entire region.

QUANTITY OF UNDERFLOW.

The investigation of the quantity and rate of underflow in Mesilla Valley, carried on in 1904 by Professor Slichter,[a] shows (pp. 11–13) that there is practically no underflow through the canyon near El Paso, but (pp. 25–29) that near Mesilla Park, where a series of experiments were made, water enters the underflow both from the river and from the drainage of the mesas. His conclusions are tabulated as follows:

TABLE 7.—*Amount of water contributed to the underflow of the Rio Grande near Mesilla Park, N. Mex., between September 20 and October 23, 1904.*

Dates.	Number of days.	Amount of ground water contributed by each mile of the river.			Amount of ground water contributed by rainfall upon mesa east of the valley per mile of river valley.		
		Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.	Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.
September 20 to October 1	11	110,500	1.28	575	40,500	0.47	211
October 1 to 9[a]	8	640,000	7.40	3,330	152,000	1.76	794
October 9 to 16	7	248,000	2.87	1,290	29,900	.35	135
October 16 to 23	7	117,200	1.36	745	5,950	−.069	−31
	33	[b] 8,900,000			[b] 1,517,000		
Average per day		270,000	3.03	1,360	45,800	.515	23

[a] Heavy flood on October 5, 1904.

[b] Total amount contributed for each mile of the valley in thirty-three days. By converting cubic feet into acre-feet it is found that the river lost 204 acre-feet of water to the gravels of the underflow in thirty-three days, and that 34.8 acre-feet were contributed by the rainfall in the same period. These amounts are for each mile of the valley.

If the amounts shown by these figures are applied to Mesilla Valley as a whole the result is large. The valley is about 50 miles long, and if the seepage amounts to 204 acre-feet of water per mile a total of 10,200 acre-feet of water was contributed to the underflow of the valley by the river during the thirty-three days included in the table

[a] Slichter, Charles S., Observations on the ground waters of Rio Grande Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905.

During the same time a total of 1,741 acre-feet was contributed by the rainfall, making a grand total for the valley of 11,941 acre-feet in the thirty-three days, or about 362 acre-feet a day.

No measurements are available for the valleys farther north, but judging from the uniformity of conditions throughout the region a like amount probably enters the ground in the other valleys.

ORIGIN OF UNDERFLOW.

The waters of the underflow are derived mainly from the Rio Grande. The rainfall is comparatively unimportant as a source of supply, since the rains are usually violent and of short duration, and although the material upon which the rain falls is very porous the greater part of the water enters the river. According to Slichter's table just quoted, the local rainfall contributes about one-seventh of the underflow. The tributary streams evidently contribute some water, but since they are small and intermittent the amount is probably negligible, leaving the Rio Grande as the main source of supply. Measurements of the flow of the Rio Grande demonstrate the fact that the river is continually losing water, the greater volume of flow being measured at the upstream rather than the downstream gaging stations. This is made clear by an inspection of the tables of discharge previously quoted (pp. 31–33). For purposes of convenient comparison the following table of totals is given:

TABLE 8.—*Discharge of the Rio Grande in acre-feet.*

	El Paso.	San Marcial.	Ildefonzo.	Cenicero.
Total for 9 years—1897–1905	6,205,066	9,168,966	10,097,307	.....
Total for 6 years recorded at Cenicero	4,101,906	5,749,197	6,431,512	2,960,123

From this table it appears that during the nine years recorded a loss of 32 per cent of the flow at San Marcial occurred between San Marcial and El Paso, a distance of about 140 miles, and that within the same period a loss of 38 per cent of the Ildefonso flow, over and above the total amount entering the Rio Grande from tributary streams during those years, occurred in a distance of about 280 miles. This loss is due to evaporation, diversion for irrigation, and absorption into the gravels. It is probable that could the discharge of the tributary streams be included the loss would be about double that shown by the river alone. To illustrate: During the nine years recorded the river lost 3,892,241 acre-feet in the 280 miles between Ildefonso and El Paso, in addition to the total discharge of such important tributaries as Galisteo Creek, Rio Jemes, Rio Puerco, Arroyo Salado, and scores of smaller tributaries. It is evident that the actual loss is much greater than that indicated by measurements of river discharge alone.

An effort has been made to determine what percentage of the known loss is due to irrigation and what to seepage and evaporation. The discussion may be found in the Proceedings of the International (Water) Boundary Commission, United States and Mexico, vol. 2, pp. 405–424. The results indicate that there is a notable loss of water over and above that diverted for irrigation. An average of three comparisons (p. 417) shows that 13 per cent of the San Marcial flow was lost by seepage and evaporation above El Paso.

COURSE OF UNDERFLOW.

All known facts point to the conclusion that a large amount of water is continually passing from the river into the underflow, and must either return to the surface and evaporate or find some underground passage by which to escape. Professor Slichter's[a] investigation proves that the escape is not through the canyon at El Paso.

The débris-filled valley west of El Paso and the apparently regular gradient of its water plane suggest that the course of the underflow may be down this old valley to the basin region of northern Mexico. On the other hand, the meager data available seem to show that this gradient is lower than that for Mesilla Valley, and that the flow should be toward the river rather than away from it, as would be the case if the course of the underflow was down the old valley. The data available at the present time are not adequate to solve this problem.

A more probable means of escape is by evaporation. Accepting Slichter's measurements of 362 acre-feet a day, contributed in Mesilla Valley, about 132,000 acre-feet of water would enter the gravels in a year. The evaporation of approximately 7 feet a year would remove from the 150,000 acres of Mesilla Valley about 1,050,000 acre-feet if the water were freely exposed, or about 8 times the amount of water entering the underflow. Over a considerable part of the valley the water plane is near enough to the surface for considerable loss by capillary action.

CHEMICAL CHARACTER OF RIO GRANDE WATERS.

MESILLA DISTRICT.

A large number of chemical analyses of waters of Mesilla Valley have been published by Goss.[b] Others have been collected from various sources and preserved in the records of the United States Geological Survey. It appears from these analyses that the total solids are not high as compared with those found in waters used elsewhere for irrigation, and that the salts are not those most deleterious

[a] Slichter, C. S., Ibid., pp. 9–13.

[b] Goss, Arthur, Principles of water analysis: Bull. No. 34, New Mexico College of Agric. and Mech. Arts, 1900.

crops. "Black alkali" (Na_2CO_3) is wholly absent from both river d ground waters. "White alkali" is abundant and accumulates as rustations of salts due to the evaporation of water brought to the rface by capillary action.

The well waters are not very satisfactory for domestic uses. The antities of magnesium, sodium, and sulfuric acid, probably esent in the form of Glauber's salt (sodium sulfate = Na_2SO_4) and psom salt (magnesium sulfate = $MgSO_4$), indicate that the waters of e valley in general are not very good for drinking purposes. The ver water contains the same substances that are found in the wells, it in smaller amounts.

Waters obtained from the mesa gravels at El Paso, Deming, and sewhere are much better for domestic use than those derived from ravels that are obviously supplied from the river. This is probably ue of the Mesilla region, though not enough data are at hand con-erning the mesa waters to permit positive statements. Two analyses ave been made of samples of water taken west of Mesilla Valley. ne, from J. F. Kilburn's well, contained 1,315 parts per million of issolved solids, and is more saline than many in the valley; the ther, from the railway well at Lanark, contained 585 parts per illion of total solids, and is better than that from many of the valley ells.

OTHER DISTRICTS.

Little can be said of the chemical character of water from the Rio rande region north of Mesilla Valley, few complete analyses being vailable. Those that could be obtained are included in Table 10. hese analyses have been collected from various sources and are early all to be found in the records of the United States Geological urvey.

In the lowlands throughout the Rio Grande region the salts con-ained in the waters accumulate as white incrustations over the soil. n Albuquerque Valley these accumulations are particularly abundant nd in many places prevent the growth of vegetation. This condition s probably caused by crude methods of irrigation. The land thus ffected has been for many years in the possession of Mexican ranch-men, who seldom take proper care of the land.

TABLE 9.—*Analyses of Rio Grande water.*[a]

AVERAGE SAMPLES TAKEN DAILY FROM ACEQUIA NEAR AGRICULTURAL COLLEGE.

[Parts per million.]

Date.	Suspended matter.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Oxides of iron, aluminum, and silicon (Fe_2O_3, Al_2O_3, SiO_2).	Sulfate radicle (SO_4).	Chlorine (Cl).	Carbonate radicle (CO_3).	White alkali.	Black alkali.
June, 1893	2,680	196	29	4	16	3	35	28	14	55	54	0
July, 1893	11,090	478	64	10	66	7	20	119	81	65	240	0
August, 1893	28,370	626	91	10	64	9	22	237	48	75	239	0
September, 1893	23,760	793	75	19	84	10	16	332	68	85	350	0
October, 1893	8,870	470	48	10	61	8	18	116	54	65	238	0
December, 1893[b]	2,610	417	54	1	73	6	19	101	62	72	226	0
January, 1894	2,570	439	60	11	57	8	12	95	68	85	230	0
February, 1904	2,160	360	35	9	65	6	7	108	68	46	245	0
March, 1904	3,380	462	56	1	84	7	15	103	74	71	242	0
April, 1904	4,300	360	51	9	40	6	24	84	42	71	170	0
May, 1904	5,890	267	39	7	30	16	21	56	23	65	129	0
June, 1904	4,070	426	55	6	59	7	14	120	49	74	224	0
Average of Rio Grande samples for 12 months	8,314	441	59	8	58	7	19	125	54	70	221	0

SAMPLES TAKEN FROM MIDDLE OF RIVER AT EARLHAM BRIDGE.

July 23, 1899	107,800	1,615	230	39	194	22	5	830	100	94	827	0
August 13, 1899	123,980	1,911	225	43	242	18	10	1,033	101	79	1,013	0
December 4, 1899	11,470	536	65	12	75	16	6	181	60	64	295	0

[a] Goss, Arthur, Principles of water analysis: Bull. No. 34, New Mexico College of Agric. and Mech. Arts, 1900, p. 72.

[b] No water in river during November.

[Parts per million.]

Location of well.	Date of taking sample.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Fe_2O_3 Al_2O_3 SiO_2.	Sulfuric radicle (SO_4).	Chlorine (Cl).	Carbonic radicle (CO_3).	White alkali.	Black alkali.
Mesilla Valley.												
Agricultural College	July, 1894	6,700	131	16	54	14	16	118	60	194	255	0
Agricultural College, old pulsometer well	....do....	1,026	161	24	113	17	10	278	165	150	451	0
Agricultural College, old pulsometer farm well	May, 1904	960	131	28	131	18	26	251	145	194	.....	0
Agricultural College, windmill well	Dec., 1901	1,041	181	34	136	17	25	25	133	135	621	0
Agricultural College, farm well	July, 1893	1,235	161	28	171	6	17	330	268	131	621	0
F. E. Lester, Mesilla Park	Aug., 1894	656	108	12	77	7	78	135	88	154	287	0
O. C. Snow, 2 miles west of Mesilla Park	Aug., 1894	633	105	14	74	7	5	142	76	154	287	0
Shalam Colony, 1½ miles west of Dona Ana	Aug., 1895	745	82	13	150	10	23	152	154	131	493	0
A. Goss, ½ mile north of Agricultural College	May, 1900	1,912	246	39	282	30	7	506	399	161	936	0
1 mile northwest of Las Cruces	Oct., 1902	680	108	80	27	.....	10	144	79	123	.....	0
G. H. Totten, Mesilla [a]	Oct., 1904	1,566	.....	.....	.....	.....	Trace.	144	232	196	.....	0
G. H. Totten, pumping plant [a]	....do....	1,123	.....	.....	.....	.....	Trace.	152	186	180	.....	0
T. Roualt, near old Fort Fillmore [a]	....do....	1,128	161	27	151	23	Trace.	159	176	215	.....	0
Francisco Misques, Bosque Seco [a]	....do....	823	115	19	109	26	6	106	163	150	.....	0
J. B. Barncastle, Dona Ana [a]	....do....	777	105	29	94	15	9	109	92	156	.....	
La Mesa district.												
J. F. Kilburn, 9 miles west of Lanark [a]	....do....	1,315	.....	.....	.....	.....	Trace	109	200	315	.....	0
Lanark, railway well	.....	585	16	14	.....	.....	.....	9	0	51	.....	.....
Jornada district.												
Rincon	Sept., 1895	1,057	48	16	30	22	19	30	156	181	.....	.....
Rincon, railway well	.....	678	110	14	.....	.....	.....	192	.....	73	.....	.....
Engle, railway surface well	.....	573	40	7	.....	.....	Trace.	27	Trace.	165	.....	.....
Engle, railway artesian well	.....	808	4	2	.....	.....	Trace.	0	0	297	.....	.....
San Marcial, railway well	.....	579	86	8	.....	.....	Trace.	82	0	140	.....	.....
Belen district.												
Belen	.....	3,139	531	108	.....	8	22	175	63	101	.....	0
J. F. Chaves	Aug., 1896	2,820	443	146	76	12	33	1,420	13	172	894	.....
Isleta railway well	.....	487	102	10	.....	.....	3	141	37	86	.....	.....

[a] Samples taken by the writer and analyzed by R. F. Hare of the New Mexico experiment station.

TABLE 10.—*Analyses of well waters from the Rio Grande region*—Continued.

Location of well.	Date of taking sample.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Fe_2O_3 Al_2O_3 SiO_2.	Sulfuric radicle (SO_4).	Chlorine (Cl).	Carbonic radicle (CO_3).	White alkali.	Black alkali.
Albuquerque district.												
Albuquerque, city well	1905	307	41	8	40	.....	68	51	15	83	.....	.....
University well, 1 mile east of Albuquerque	1904	213	30	8	25	.....	45	28	10	70	.....	.....
Military well, 7 miles east of Albuquerque	1904	197	34	2	31	.....	30	24	2	75	.....	.....
Albuquerque, railway well		326	61	8	.....	.....	.....	61	.....	71	.....	.....
Albuquerque, railway-shop well		365	64	13	.....	.....	.....	36	.....	106	.....	.....
Bernalillo, railway well		828	55	8	.....	.....	9	Trace.	Trace.	240	.....	.....
Thornton, railway well		398	60	14	.....	.....	Trace.	Trace.	Trace.	175	.....	.....
Santa Fe district.												
Santa Fe city supply, from Santa Fe Creek	May, 1899	40	5	1	4	2	10	2	1	11	10	0
Do	Jan., 1900	85	14	4	3	3	8	1	6	27	14	0

APPLICATIONS.

UTILIZATION OF UNDERFLOW.

Shallow wells.—The flood-plain material of the lowlands along the river, although saturated, does not, in general, allow the water to pass through it freely enough for the successful use of shallow irrigation wells. In certain places, however, as at Belen, where the railway well is dug in coarse sand, large volumes of water are readily obtained from this material.

Deep wells.—Beneath the fine silt of the flood plains there is coarser material, from which large quantities of water are obtained, as in the various irrigation wells in Mesilla Valley and the city wells at Albuquerque. A considerable amount of fine sand and silt occurs in the gravel beds as well as in the flood-plain deposits and prevents the rapid movement of water through them, causing the high lift and to a large extent the great cost shown in Table 6. In spite of its great cost, however, the pumping of water for irrigation has proved profitable in El Paso and Mesilla valleys. In the valleys farther north the gravels are apparently coarser and water could probably be pumped at less cost than in Mesilla Valley. In Mesilla Valley the quantity of water recovered might be greatly increased by additional wells, and pumping plants might be established with profit in Palomas, Socorro, Belen, and Albuquerque valleys. Although the data at hand show that in this region, as compared with other valleys of the Southwest, the underflow is small and the water not readily obtainable on account of the fineness of the material in which it is contained, enough water may be pumped from the sands and gravels to warrant development.

Seepage ditches.—The construction of seepage ditches as a means of obtaining the waters of the underflow has been proposed for the Rio Grande Valley, but no such ditches have been dug, and the large proportion of fine sand and silt is apparently unfavorable to this method of procuring the water.

WATER STORAGE.

The alternation of broad basins and narrow canyons along the course of the river is apparently favorable to the establishment of storage reservoirs, but at only two points are the rock formations suitable for the construction of masonry dams. These are in El Paso canyon, the dam site of the proposed International reservoir, and at Elephant Butte, the dam site of the proposed Engle reservoir.

From a geologic standpoint the Engle reservoir is much more favorable for water storage than the International reservoir. The most important geologic considerations favoring the location of a storage reservoir in Engle Valley are (1) a narrow canyon with hard rock

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[Water-Supply Paper No. 188.]

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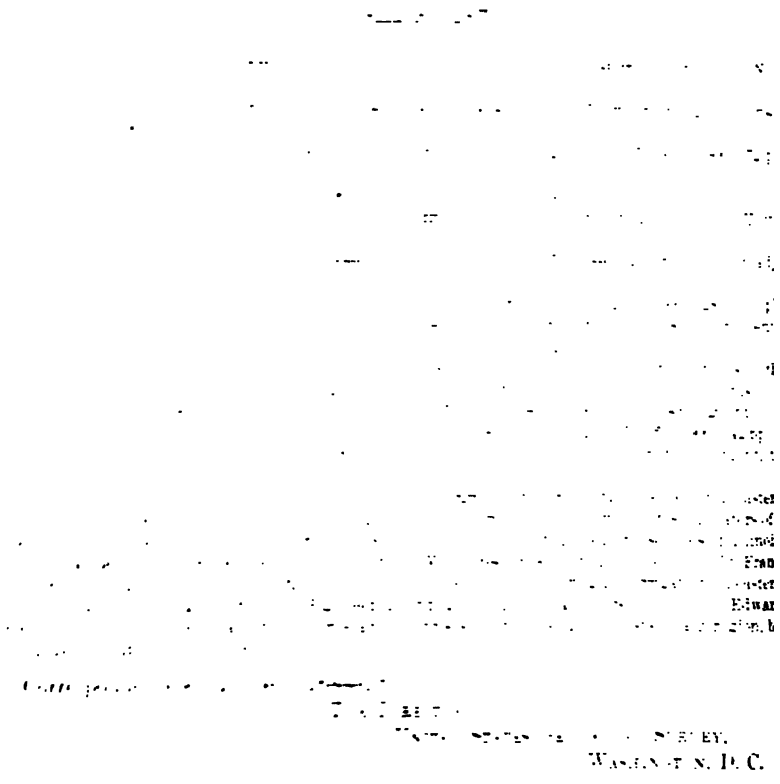

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THE PREVENTION OF STREAM POLLUTION BY STRAWBOARD WASTE

BY

EARLE BERNARD PHELPS

IN COOPERATION WITH THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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THE PREVENTION OF STREAM POLLUTION BY STRAWBOARD WASTE.[a]

By EARLE BERNARD PHELPS.

INTRODUCTION.

The disposal of the waste liquors resulting from the manufacture of strawboard forms one of the most important problems connected with the prevention of stream pollution. In 1900 the total production of strawboard in the United States was 157,534 tons at 59 factories. For each ton of strawboard manufactured there were discharged into the streams about 65,000 gallons of waste liquor that contained 1,173 pounds of straw and mineral matter and 490 pounds of lime. The total waste discharged into the streams in 1900 amounted to 10,239,710,000 gallons of liquor, containing 184,777,382 pounds of straw and mineral matter and 77,191,660 pounds of lime. This enormous waste was discharged by 59 plants of various sizes, but as most of these mills are along small streams the resulting pollution is very apparent. Some idea of the amount of this pollution may be obtained from Pl. I, *B*. The baled straw shown is a three months' supply for a mill having an output of 30 tons a day. In three months one third of this straw will be discharged into the stream as waste matter.

The problem of the disposal of the waste water has been studied by Prof. R. L. Sackett, of Earlham College,[b] and the present investigation is a continuation of the work of Sackett along new lines. In approaching the problem it is necessary to keep constantly in mind the economic conditions affecting the industry. The low selling price of the product, the immense volume of waste water necessary, and the fact that competition between strawboard and other forms of cheap board is active, make it quite impracticable for the manufacturers to

[a] This investigation was made in cooperation with the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology.

[b] Water-Sup. and Irr. Paper No. 113, U. S. Geol. Survey, 1905, pp. 9–35.

adopt any process involving serious expenditures. The solution of the problem must be sought in a process which will show an actual saving. Aside from the matter of the recovery of by-products of commercial value, this means that the process must compete in cost with the present unsatisfactory sedimentation methods employed at many of the mills, to the cost of which may reasonably be added the almost constant expense of lawsuits and injunction proceedings, the latter in some cases causing the closing of the mill.

As a result of this study it has been found that sedimentation of the waste water for a short period, followed by filtration thru sand at high rates—the so-called mechanical filtration, but without coagulants—will produce an effluent from which more than 90 per cent of the suspended organic matter has been removed. This effluent, while not ideal, is probably purified to such an extent that, allowing a factor of safety of 2 for impurities in the stream, it may be discharged into streams having a minimum flow of twice the discharge of the mill without producing a nuisance. The cost of filtration by this process, after the initial cost of installation, is practically reduced to the cost of pumping the wash water. The final result is a heavy sludge, whose volume is less than 5 per cent of the initial volume of the waste. Ultimate disposal of this sludge could be made either by discharge over land for spontaneous evaporation, by evaporation by means of artificial heat, or by filter pressing. The sludge has some value as a fertilizer, and there are also certain commercial uses to which it seems to be adapted.

THE MANUFACTURE OF STRAWBOARD.

The following description of the manufacture of strawboard is taken from Professor Sackett's paper:[a]

STEAMING IN ROTARIES.

The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a "rotary" * * * is filled with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. * * * This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark-yellow, pulpy mass. This "stock," as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the Journal of the Society of Chemical Industry says:[b]

"The chemical action of the milk of lime on the incrusting materials surrounding the straw fiber is not a vigorous one. These incrusting materials are not completely,

[a] Water-Sup. and Irr. Paper No. 113, U. S. Geol. Survey, 1905, pp. 13–15.
[b] For February 28, 1894, p. 101.

A. VIEW OF STRAWBOARD MILL.

B. PILES OF BALED HAY

One-third by weight will be wasted in three months.

nor, indeed, to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water."

The yield of pulp at this point will be from 75 to 80 per cent of the weight of the original material. * * *

The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent of water and from 6 to 7 per cent of lime. This is equivalent to from 12 to 14 per cent of lime in the dry straw. Since the original charge of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent lime, practically none of the latter has drained out with the condensed steam. This drainage from the stock piles forms but a small part of the waste sewage. It is straw colored and very turbid, carrying a small quantity of fiber broken fine in the rotaries.

WASHING.

This process is much more drastic, and it is here that the great volume of waste is produced.

The stock is run thru washing machines for the purpose of removing the lime. * * * The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, thru which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times thru the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. * * *

DRYING.

After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats, where it is mixt with large quantities of water and past over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are prest down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in thru hollow bearings. As the pulp passes on thru the train it is constantly prest and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish.

THE DISPOSAL OF WASTE LIQUOR.

METHOD IN USE.

At present, so far as can be learned, the only method of treating the waste liquor in actual use by the manufacturers is that of prolonged sedimentation in open fields. The overflow water from these fields is not satisfactorily clarified at all times of the year. During cold weather it is fairly clear and can be discharged without serious harm. During the summer, however, a very offensive fermentation takes place in the accumulated sludge, giving rise to objectionable odors and blackening the water. At such times the aim is to hold all the waste water in the ponds, trusting to evaporation and to the storage capacity of the ponds until cold weather again relieves the situation and the increased flow of the stream permits a discharge of the surplus water stored. The most serious objection to this process, which seems to be satisfactory to riparian owners below, is the fact that these ponds are continually filling up with a soft mud, which destroys their function as sedimentation basins and renders them useless for other purposes. The time must come, even in the most favorable situation, when additional land can not be afforded for this purpose. A second objection is that the accumulated sludge is held for years and slowly putrefies. The organic matter of the waste is but slightly nitrogenous and is fairly stable. It probably contains some reducing sugars capable of rapid fermentation if kept in concentrated form and if given at the same time some nitrogenous matter. The slow decomposition of the stable straw material supplies the necessary nitrogen, and the result is a very rapid multiplication of the putrefactive organisms and an accompanying offensive putrefaction. Laboratory experiments have shown that the soluble sugars by themselves, as found in a filtered sample of the waste water, do not ferment or decompose, and that even the unfiltered waste is not subject to a quick putrefaction such as characterizes sewage matter. In fact, bottles have been stored for over a year without any evidence of fermentation, and it may very reasonably be held that the necessary nitrogen comes largely from the bottom of the ponds, rather than from the sludge itself. Inspection of the stream below one of these ponds showed that, while putrefaction was barely noticeable and not at all offensive in the pond itself, the admixture of some of this water with that of a small brook, highly polluted with the refuse of a slaughterhouse, had immediately a very offensive result. Investigation of the condition of the streams below these mills reveals the fact that the most serious nuisance generally occurs at a point very remote from the mill itself. It is directly caused by the slow decomposition of material deposited in the bed of the stream. The conditions are doubtless aggravated by the simultaneous precipitation of

other polluting substances, notably sewage, brought about by the free lime of the strawboard waste.

The effective solution of the problem lies in the rapid separation of the solid matter from the dissolved sugars and lime and a subsequent dilution of the latter so that they shall be innocuous. The insoluble material when dry is entirely stable. The present system, therefore, is not only unsatisfactory from the economic side, but it works on a wrong principle for satisfactory purification in that it encourages putrefaction.

The cost of these ponds at four of the larger mills of the United Box-board and Paper Company, as stated by an official of that company, has been, in round numbers, to date, $10,000, $15,000, $18,000, and $8,000. In the last case the results were still unsatisfactory, and after a considerable expenditure on other experiments the company has been obliged to close this mill.

PROPOSED METHODS.

CENTRIFUGAL SEPARATION.

Centrifugal separation of the solid matter from the liquor was tried at Tiffin, Ohio, in 1904. It has not been possible to obtain more definite information concerning those experiments than is contained in the trade papers of that time. It is understood, however, that the results were quite satisfactory, but that the cost of operation was prohibitive. The account referred to (see Paper Trade Journal, February 2, 1905) states that the effluent was clear and colorless and that the residue was found by analysis to be valuable as a fertilizer.

PRECIPITATION WITH CARBON DIOXIDE.

As a result of his investigations Sackett concluded that plain sedimentation would remove about 10 per cent of the suspended solids in twenty-four hours and that during the ensuing twenty-four hours the additional removal was very slight; that good purification could be effected by chemical precipitation only by using sulfate of aluminum in excessive amounts and at an entirely prohibitive cost; that sulfate of iron gave inferior and unsatisfactory results, and, finally, that by a process of precipitation with carbon dioxide and lime an average removal of 85 per cent of the suspended matter could be effected.

The process recommended by Sackett consists in (*a*) saturation of the waste water with carbon dioxide to form bicarbonate with all the lime present; (*b*) addition of lime equal to that already present to form a normal carbonate; (*c*) sedimentation of the precipitated carbonate and consequent dragging down of some of the organic matter, and (*d*) filtration of the resulting clarified liquor thru sand at rates of 500,000 to 2,000,000 gallons per acre per day. This process has never been used by manufacturers so far as the writer is aware.

It does not appear from Sackett's report that he tried the simpler but equivalent process of saturating one-half the total volume with carbon dioxide and then mixing with the other half. Such treatment would doubtless have precipitated the calcium fully as well, with a saving of one-half the carbon dioxide and all the lime required by the process recommended. An examination of the analytical data shows that the removal of suspended organic matter accomplished by the precipitation and sedimentation processes varied from zero to 75 per cent, with a mean value of 37 per cent. Experiments on plain sedimentation, made by the writer both in the laboratory and on a large scale in the field, show it to be equally efficient for the removal of suspended organic matter. The fact is that the precipitated carbonate of calcium is very finely divided and has no value as a coagulant. The process is valuable to remove the lime, if that be desirable. It hardly seems, however, that the value of discharging a lime-free effluent into the hard waters of the Middle West is at all commensurate with the cost of treatment.

LABORATORY INVESTIGATIONS.

CHEMICAL STUDY OF THE SOLUBLE MATTER.

Several barrels of the strawboard waste liquor were shipped to Boston from one of the mills of the United Box-board and Paper Company, and on this material a series of investigations was carried out. Sackett's experiments with various coagulants were repeated and his results confirmed. It was found that the poor results obtained with any but excessive amounts of iron or aluminum sulfate were due to the presence of a substance in solution which forms soluble combinations with those metals. This substance was isolated by precipitation with hydrochloric acid, and after repeated purification was found to have the following properties: It is an organic acid, probably related to the humic or ulmic acids of the soil and peaty waters. It exists in the waste water as a calcium salt, having partially neutralized the free lime used in the digestion. It is precipitated by strong acids, coming out as a dark-red substance which turns brown on slow oxidation in the air. It can be redissolved in a solution of sodium carbonate, giving a garnet-red solution. It dissolves in alcohol, giving a deep-red color, but oxidizes to a brown insoluble substance. Its calcium and aluminum salts are not soluble when prepared from the insoluble acid, but the acid can not be precipitated from its solutions by these metals. It appears that there are formed colloidal suspensions of the calcium and aluminum salts. The solutions have a bright-yellow color and colloidal appearance. The iron compound is similar but of a green color. The sodium salt appears to be soluble and to dissociate into deeply colored acid ions.

A second substance isolated from the waste has the following properties: It is soluble in water and not precipitated by any of the common precipitants, including alum, ferrous sulfate, lead acetate (normal or basic), carbonates, hydrates, or acids. It is responsible for a large part of the color of the water and can not be removed by any practical method.

These two substances with the lime make up the greater part of the dissolved material. They are entirely stable and do not undergo putrefactive change when stored in the incubator, either alone or mixt with varying proportions of tap water. In addition to these substances small amounts of reducible sugars are present. The amount is so small that in any material dilution of the liquor the dilution of these sugars will prevent their manifesting themselves as putrefactive agents. These sugars are probably responsible for the slow fermentation in the sedimentation fields after the lime has been sufficiently removed to allow the action to proceed.

PRECIPITATION EXPERIMENTS.

Substances in suspension may be removed by filtration or by sedimentation. When the material is finely divided or of low specific gravity, either process may sometimes be assisted by the application of suitable coagulants. These tend to clot the small particles into larger flakes, and by their own greater density carry the clotted material to the bottom. Two chemical substances are required, as a rule, to produce the necessary precipitation, one of which is generally the calcium bicarbonate found normally in the water. This calcium salt reacts with the sulfates of certain metals, notably iron or aluminum, to produce the sulfate of calcium and the hydrates of the corresponding metals. In the present case there is a large amount of free lime in solution. It would seem, therefore, that precipitation might be brought about by the addition of either copperas or alum. Experiments showed that copperas failed to react at all and that fair results could be obtained with alum, but only at a prohibitive cost. As will be seen in the accompanying tables of results, the removal of organic matter by alum was much better than that obtained by plain sedimentation.

Results of precipitation experiment on strawboard waste.

Sample.	Suspended solids.	
	Present.	Removed.
	Parts per million.	*Per cent.*
Raw waste	1,350	
Waste after 2 hours' sedimentation:		
With coagulant[a]	120	91
Without coagulant	560	59

[a] The coagulant used was alum in the proportion of 10 grains of sulfate of aluminum per gallon.

Increasing the amount of aluminum sulfate gave practically the same result. Smaller amounts gave indefinite and at times negative results. The use of 10 grains per gallon of sulfate of aluminum at 1 cent a pound would represent a cost of about 43 cents per ton of finished product of the mill. The studies on the nature of the dissolved material already referred to explain these poor precipitation results with alum. Soluble compounds are formed with the organic acid, instead of aluminum hydrate, the desired coagulant.

Experiments were made with carbon dioxide according to Sackett's procedure, and his results were confirmed. There was but a slight removal of suspended organic matter—about 30 per cent—which could be produced equally well by plain sedimentation. In fact, under actual working conditions sedimentation was found to be even more effective.

SEDIMENTATION EXPERIMENTS.

In a study of plain sedimentation it is important to know the rate of sedimentation and how this varies with the time. With satisfactory data on this point it is possible to estimate the amount of clarification which may be expected to result from any given period of sedimentation and to establish the most suitable period for the case in hand. It was observed early in this work that apparently a large portion of the suspended solids settled out in a very short time, and that to all appearances further improvement was extremely slow. The determinations of the total solids given in the following table show that there is no practical advantage in sedimentation for a period of much over one hour:

Effect of sedimentation on strawboard waste.

	Suspended solids.	
	Present.	Removed.
	Parts per million.	*Per cent.*
Liquor at beginning of experiment	1,344	.....
Supernatant after 1 hour	548	59
Supernatant after 12 hours	494	63

SUMMARY.

As a summary of the laboratory investigations, it may be said that the removal of the dissolved coloring and other organic matter and the lime in an economical way is impractical; that by plain sedimentation a removal of suspended material practically as good as the best removal observed with the use of a coagulant can be accomplished; and that a sedimentation period of one hour is sufficient for the removal of about 60 per cent of the suspended solids, a longer period increasing this removal but slightly. For the removal of the remainder of the suspended matter, there remains but one process—filtration. It was therefore decided to make an actual field test of this method of

purification. The very large amounts of suspended matter to be handled seemed to eliminate at the outset the possible use of slow sand filtration, so that it was obvious that mechanical filtration at high rates and with some provision for removing the accumulated sludge from the surface of the filters was the only system applicable to the problem.

FIELD INVESTIGATIONS.

ACKNOWLEDGMENTS.

In March and April, 1905, a visit was made to one of the mills of the United Box-board and Paper Company, at Urbana, Ohio. Every opportunity was given the writer to make a thoro study of the processes of manufacture, and it is here desired to make suitable acknowledgments to Mr. Rush E. Evans, division manager, and to Mr. D. C. Amerine, superintendent, for the many courtesies extended, both on that occasion and during the subsequent visit for the installation of an experimental plant.

AMOUNT OF WATER USED.

It was found that conditions were favorable for measuring the entire volume of waste water, as it left the mill in a waste flume. As a check on these measurements, observations of the rate of operation of the pump were made, all the water used being pumped from a large well under the mill.

A rectangular flume, whose mean width was 1.96 feet, was used for these measurements. A distance of 100 feet was measured off in a portion where the slope was practically constant. To determine the velocity of flow at various elevations in the flume, a float was used which was nearly as long as the width of the flume and was provided with vanes underneath, so that it always floated squarely across the flume. The following observations are the mean of a large number made at various elevations of water in the flume:

Mean depth, velocity, and flow of waste water in flume of mill of United Box-board and Paper Company, Urbana, Ohio.

Depth of water.	Velocity of flow.	Area of cross section.	Flow.
Foot.	*Feet per second.*	*Square foot.*	*Cubic feet per second.*
0.19	3.1	0.37	1.1
.25	3.8	.49	1.9
.29	4.0	.57	2.3
.31	4.2	.61	2.6
.33	4.3	.65	2.8
.37	4.5	.72	3.2

These values of the depth and the corresponding flow were then plotted. The most probable line was drawn thru them, and that curve was used as the true rating curve of the flume in the subsequent calculations.

During the two hours from 10.45 a. m. to 12.45 p. m., March 30, a test run was made to determine the total flow. The following readings of the elevation of the water in the waste flume were made, and from these readings has been calculated the total flow for the two hours:

Flow of waste water in flume of mill of United Box-board and Paper Company, Urbana, Ohio, March 30, 1905.

Time.	Depth.	Flow.	Flow for 15-minute period.	
			Mean rate of flow.	Total flow.
	Feet.	*Cubic feet per second.*	*Cubic feet per second.*	*Cubic feet.*
10.45 a. m	0.29	2.3		
11 a. m	.29	2.3	2.3	2,100
11.15 a. m	.33	2.8	2.6	2,400
11.30 a. m	.33	2.8	2.8	2,500
11.45 a. m	.33	2.8	2.8	2,500
12 m	.33	2.8	2.8	2,500
12.15 p. m	.38	3.4	3.1	2,800
12.30 p. m	.36	3.1	3.2	3,000
12.45 p. m	.33	2.8	3.0	2,700
Total				20,400

This total flow of 20,400 cubic feet in two hours represents an average flow of 2.69 cubic feet per second.

A few measurements were made of the water running in the waste flume when the beaters were not running and again when the paper machine was stopt. The flow from the machine was found to be fairly constant at 1.4 cubic feet per second, and the beaters were found to discharge amounts of 1.2 to 1.8 cubic feet per second, depending on the number of beaters in operation at the time.

During the test run observations of the rate of operation of the pump were made at short intervals. The pump was a double-acting duplex Smith-Vaile pump, with water cylinders 14 inches in diameter and with a stroke of 15 inches. Slip being neglected, the capacity of the pump is, therefore, 1.335 cubic feet per stroke, or 5.340 cubic feet per complete revolution. Following are the observations made on the pump and the calculated rate of pumping:

Discharge of pump at mill of United Box-board and Paper Company, Urbana, Ohio, March 30, 1905.

Time.	Revolutions per minute.	Discharge.	Time between observations.	Discharge of pump between observations.	
				Mean.	Total.
		Cubic feet per second.	*Seconds.*	*Cubic feet per second.*	*Cubic feet.*
10.45 a. m	31	2.28	0		
11 a. m	30	2.67	900	2.43	2,457
11.15 a. m	30	2.67	900	2.67	2,403
11.30 a. m	30	2.67	900	2.67	2,403
11.45 a. m	30	2.67	900	2.67	2,403
11.55 a. m	30	2.67	600	2.67	1,602
Do	[a]40	3.58			
12.25 p. m	40	3.58	1,800	3.58	6,444
12.45 p. m	38	3.57	1,200	3.48	4,176
Total pumped					21,888

[a] Changed.

During the test four of the seven rotaries were filled. Two hundred and fifty cubic feet of water are required for each rotary, or 1,750 cubic feet for the seven. Since all seven are filled only once in twenty-four hours the water used in this process amounts to 73 cubic feet per hour for the whole day. The water so used during the two hours of the test was, however, 750 cubic feet, an excess of 604 cubic feet over the normal mean consumption. The amount pumped must, therefore, be corrected by this amount. The elevation of the water in the supply tank was 1 foot greater at the end of the test than at the start. The diameter of the tank is 12 feet. This storage amounts, therefore, to 113 cubic feet, and must also be applied as a correction. A small stream of water was being wasted from the engine condenser. This stream was roughly estimated by float measurements to be about 0.3 cubic foot per second, or 2,160 cubic feet during the two hours of the run. These three corrections amount to 2,888 cubic feet, which is to be subtracted from the total pumped, 21,888 cubic feet, leaving a net pumpage of 19,000 cubic feet for two hours, or 2.64 cubic feet per second, a result in close agreement with the 2.69 cubic feet per second measured in the waste flume.

RAW MATERIAL AND FINISHED PRODUCT.

During this test run, careful weighings were made of the amount of finished board produced. The figures were as follows:

Product of mill of United Box-board and Paper Company, Urbana, Ohio, for two hours, March 30, 1905.

	Pounds.
Gross product	4,841
Waste and trimmings	196
Net product	4,645

Dividing the total amount of waste liquor, 20,400 cubic feet, by the amount of net product gives 8,780 cubic feet, or, roughly, 65,000 gallons per ton of product. As the daily product of this mill is about 30 tons, about 1,900,000 gallons of waste water are discharged each day.

The charge of one rotary was carefully weighed. There were used 133 bales of straw, of an average weight of 102 pounds, or a total of 13,600 pounds of straw. The amount of lime was weighed, but the weight was somewhat in excess of the average amount used, as determined by the total weekly consumption of lime. The latter figure, which is 2,100 pounds per charge, will therefore be used. The total amount of straw used in the 7 rotaries is accordingly 95,200 pounds per day, and of lime, 14,700 pounds per day. Subtracting from this the 60,000 pounds of finished product leaves a waste of 35,200 pounds of vegetable and mineral matter from the straw and 14,700 pounds of lime, which is carried off each day in the 1.9 million gallons of water.

Calculated into parts per million, these figures give about 2,400 parts of straw material and about 1,000 parts of lime. Analyses of average samples of the waste water gave about 600 parts of calcium or 840 parts of lime per million. The difference is due partly to the loss of lime during the draining of the digested pulp and largely to impurity of the lime.

CHARACTER OF THE MACHINE WATER.

Determinations of the lime were made on the well water and on the various waste waters. It was found that the greater part of the lime is washt out in the beaters and that the water from the machine contained but little lime in excess of that in the raw water. The actual figures were:

Calcium in waste water.

[Parts per million.]

Well water	238
Beater water	1,164
Machine water	380

A rough determination of the impurities was made by precipitating the lime and organic matter, with a large excess of alum. A 6-inch column of the beater water gave a layer of precipitate an inch thick, while the amount obtained from the machine water was too small to be measured.

MECHANICAL FILTRATION.

In May, 1906, a small experimental filter was installed at this mill, in order to obtain some practical data on the efficiency of treating the waste by mechanical filtration. The filter and accessories were loaned by the New York Continental Jewell Filtration Company, of New York, thru the courtesy of Mr. R. E. Milligan, assistant general manager, and the expenses of shipment and installation were borne by the paper company.

DESCRIPTION OF THE FILTER.

The filter used is shown in fig. 1. The waste water, after passing the regulating butterfly valve, divided into two streams and entered the bottoms of the two sedimentation tanks. These tanks were of cypress, each having a diameter of 4 feet and a depth to the overflow line of 3.2 feet. The capacity of the two was 603 gallons. The water was delivered to the tanks thru half-inch holes in the sides of risers extending to the surface. The vertical distribution was, therefore, very uniform. Vertical baffles caused the water to flow completely thru the tanks, and a funnel-shaped overflow collected the clarified water from the surface of each tank and delivered it to the surface of the filter. The filter proper was of galvanized iron, set

upon a cast-iron base, provided with a false bottom of fine brass screening. The diameter of the filter was 20 inches, and its total depth to the false bottom was 5 feet. Suitable connections and valves

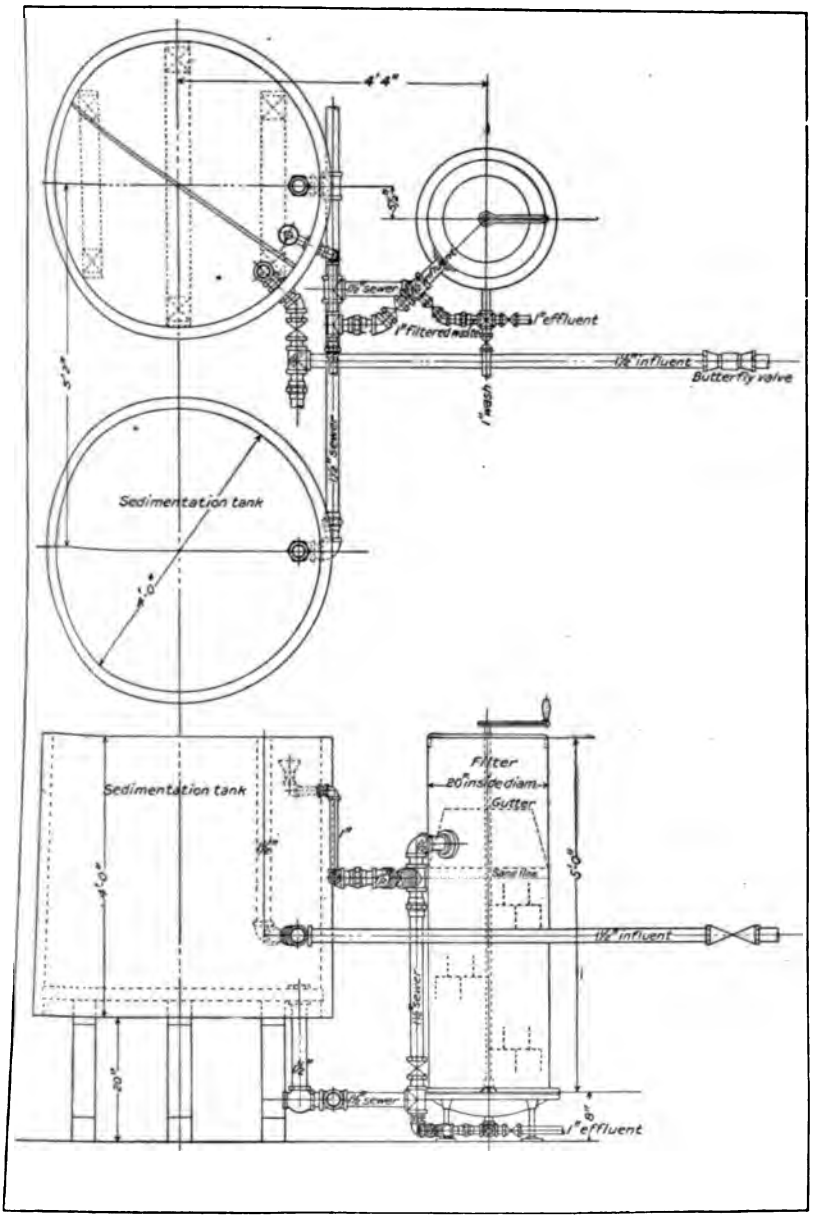

FIG. 1.—Details of experimental filter.

were provided, as shown in the drawing, so that the influent and the effluent water could be cut off, a stream of wash water could be

admitted from the bottom, and the dirty wash water, overflowing from the top, could either be wasted thru the sewer connection or returned to the sedimentation tanks. The device for stirring the sand during washing was operated by hand. Wash water was supplied from an elevated tank under such a head that a maximum flow of 25 gallons per minute, or 12 gallons per square foot per minute, was possible. A flow of about 8 gallons per square foot per minute was generally used. Suitable connections were also made between the bottoms of the sedimentation tanks and the sewer. A 50-gallon barrel at the end of the sewer line served as a measuring tank for the wash water or the sludge. The rate of flow thru the filter was regulated at the outlet by a standard orifice, a sectional view of which is shown in fig. 2. The orifice itself was a trifle over seven-sixteenths

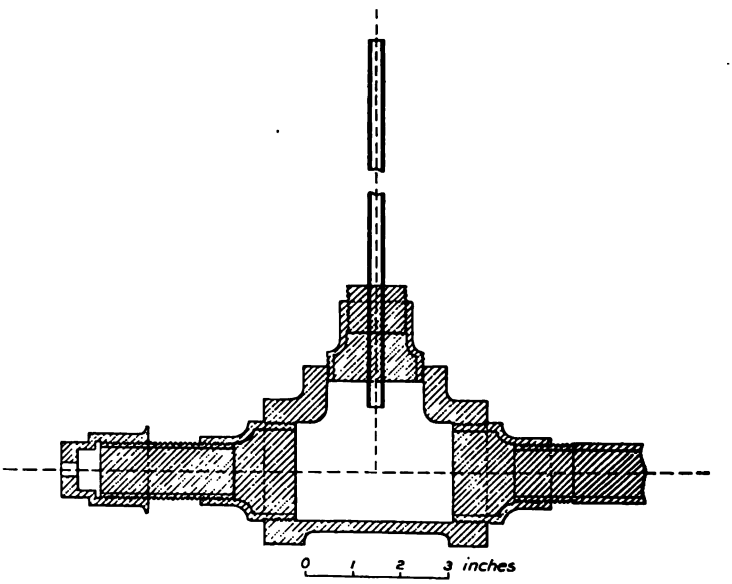

FIG. 2.—Sectional view of standard orifice.

of an inch in diameter. The brass cap containing the orifice was screwed over a nipple of 1-inch pipe, which was in turn connected with a 2-inch tee. The opposite side of this tee was connected by a short pipe to the valve regulating the outflow, and a glass tube, fitted to the upper opening of the tee, permitted the static head on the orifice to be read at any time. The large sectional area of the tee as compared with that of the orifice reduced the velocity of approach to a negligible value. This device was roughly calibrated in the field and was subsequently carefully calibrated by discharging into a large measuring tank. The rough field values were found to be substantially correct.

A SEDIMENTATION TANKS AND FLOAT REGULATOR.

B. EXPERIMENTAL FILTER, SEDIMENTATION TANKS, AND MEASURING TANK.

The rate of inflow to the tanks was adjusted to the rate of filtration by the butterfly valve, actuated by a float in one of the tanks (not shown). The filter was filled to a depth of 3 feet with clean 16–30 beach sand, i. e., sand which will all pass a screen with 16 meshes to the linear inch and be retained on a screen with 30 meshes. The water line was 18 inches above the surface of the sand.

The appearance of the filter and sedimentation tanks as they were set up is well shown in Pl. II. Pl. II, *A*, shows the sedimentation tanks, the influent pipe and controlling valves, and the lever arm of the float operating the butterfly valve. Pl. II, *B*, shows the filter itself, the loss-of-head gage, and the connections with the tanks and the sewer. To the extreme right is the measuring tank, and passing between the two tanks on the ground the wash-water pipe line can be seen. The outlet of the filter is hidden from view behind the mound of earth in the foreground.

PRELIMINARY SEDIMENTATION.

A number of tests were first made to determine the rate of change in the loss of head during filtration with varying periods of preliminary sedimentation. A uniform rate of filtration of 3.25 gallons per minute, equivalent to a rate of 100,000,000 gallons per acre per day, was maintained. The capacity of each of the sedimentation tanks was 300 gallons to the overflow line, so that one tank alone gave a mean storage capacity of one and one-half hours and the two tanks taken together three hours. During the first series of tests both sedimentation tanks were used. The following table shows the relation of loss of head to the quantity of water filtered, the run in question being a fair average of the five made in this way. The results of all the five tests were practically identical.

Relation of loss of head to quantity of water filtered.

Time.	Elapsed time.	Quantity filtered.	Loss of head.
	Minutes.	*Gallons.*	*Inches.*
9.35 a. m.	0	0	4
9.50 a. m.	15	49	7
10.05 a. m.	30	98	8
10.30 a. m.	55	178	12
1.40 p. m.	55	178	11
2 p. m.	75	211	14
2.30 p. m.	105	308	20
3 p. m.	135	406	28
3.30 p. m.	165	504	40
4 p. m.	195	600	55

Between 10.30 a. m. and 1.40 p. m. test shut down. No liquor.

The maximum loss of head possible was 55 inches. The mean results from the above and four similar tests gave 585 gallons of water filtered before the loss of head was total.

One of the sedimentation tanks was then cut out of service and th period of sedimentation correspondingly reduced to one and one-ha hours. Four runs to determine the maximum amount which could b past under the conditions gave a mean result of 575 gallons, in pra tical agreement with that of the first series. It is apparent that period of one and one-half hours was sufficient for the removal of th portion of the suspended matter which can be removed by sediment tion. An examination of the water during sedimentation in a gla vessel tended to confirm this conclusion. The suspended matter a pears to be of two distinct kinds. One is very finely divided and ligh and does not settle out even on prolonged sedimentation. The othe is granular and heavy and settles rapidly and completely. It was n convenient with the apparatus at hand to reduce further the period o sedimentation. The laboratory experiments quoted earlier in th paper indicated that a period of one hour would accomplish practicall the same result as more prolonged sedimentation.

AMOUNT OF WASH WATER.

The pressure on the wash-water pipe line was sufficient to give a upward flow thru the filter of 25 gallons per minute, or about 12 ga lons per minute per square foot of surface. In practise, flows of 8 t 10 gallons per square foot per minute were used. After each of th test runs just described, the filter was washt with an amount of wate varying from 50 to 100 gallons for two and one-half to five minute the wash water being carefully measured. Observations of the su face of the filter showed plainly that the shorter period of washin was sufficient and that the longer periods did not in any case increas the quantity filtered during the succeeding run. The materi deposited on the surface was exceedingly light and finely divided an required but little water for its removal. The stirring device use was not well adapted to the purpose, since there was little penetratio of the sand by the suspended material. An air blast or some devi which would thoroly agitate the surface before washing wou undoubtedly make possible the use of still less wash water. Allowin 50 gallons for each wash, with an average quantity of 575 gallons p run filtered, gives a little less than 9 per cent wash water.

The loss of head in these tests bears out a fact of general observ tion, that the loss of head increases at a fairly constant rate durin the run. Such being the case, it is quite evident that with a deep filter the quantity filtered between washings would be proportionate increased. The amount of wash water would, on the other han remain constant or increase but slightly. It is therefore safe to s that with a filter having an available loss of head of 9 to 12 feet

average run of six hours or more could be maintained and the amount of wash water could be reduced to less than 5 per cent.

DISPOSAL OF WASH WATER.

The process, as thus far described, is merely one of concentration of the suspended matter. If the above estimate of 5 per cent of wash water be correct and the filtered water be used for washing, the net result of the process would be the separation of 95 per cent of the water in comparatively clean form, leaving the total suspended impurity in the remaining 5 per cent of the water. This water might be spread upon a small area of land to evaporate, it might be evaporated by artificial means, or, if preferable, it might be filter prest; but the most economical way to dispose of it is to return it directly to the sedimentation tanks. The material on the filter is so prest together into small lumps that it settles rapidly. The problem of the ultimate disposal of the sludge from the tanks will be taken up in another place.

CHARACTER OF EFFLUENT.

Complete chemical analyses of the waters before and after treatment during these experiments were neither desirable nor feasible. The determination of the total organic solids contained in the waters is the only analytical determination which would be of service in estimating the efficiency of the process. This determination might have been made by the usual indirect method, i. e., by the difference between the total and the fixt or mineral solids. That determination is, however, not well adapted to field conditions, and small changes in the organic content would be entirely masked by the relatively large amount of mineral residue present. It was found in the laboratory studies on the waste liquor that estimating the efficiency of the various precipitation methods on the basis of this organic-solids determination and also on the basis of the oxygen-consumed method gave practically the same results. In other words, the organic matter present is fairly homogeneous in character, as might well be expected, and the oxygen-consumed figures, altho purely relative, are therefore a reliable measure of the amount of organic matter present. This test, therefore, and the determination of the turbidity, or suspended solids, by the well-known Jackson turbidimeter method, were used in this work to determine the quantity of the organic and the suspended matter, respectively.

During the two three-hour runs samples for analysis were collected every ten minutes from the raw liquor, sedimented liquor, and final effluent, the small samples being mixt together to obtain an average

sample for the run. In both cases the rate was maintained at 3.25 gallons per minute. The following data of the test were obtained:

Data from test run of filter.

Test No.	Duration.	Loss of head.		Quantity filtered.
		Initial.	Final.	
	Hours.	*Inches.*	*Inches.*	*Gallons.*
7	2.9	4	55	566
8	3	3	55	585

The chemical analyses for the two sets were very similar. The following table shows the mean values obtained:

Analyses of raw liquor, settled liquor, and effluent.

	Parts per million.	Per cent removed.
Raw liquor.		
Oxygen consumed:		
Total	9,400	.....
Dissolved	2,000	.....
Suspended	7,400	.....
Suspended solids	28,000	.....
Settled liquor.		
Oxygen consumed:		
Total	6,200	34
Dissolved	1,600	20
Suspended	4,600	38
Suspended solids	4,400	84
Effluent.		
Oxygen consumed:		
Total	2,200	77
Dissolved	1,700	15
Suspended	500	93
Suspended solids	575	98

The appearance of the effluent frequently changed materially during the run. Contrary to expectations and general experience, the best effluent was always obtained during the early part of the run. The very first portions of effluent were generally slightly turbid, after which a perfectly clear water came thru, as a rule, entirely free from suspended matter. This state of affairs continued until the loss of head had reached about 6 or 8 inches, when the effluent suddenly became turbid and continued so uniformly until the end. The inference was that under a tension or pull on the surface film represented by about 6 to 8 inches of head the finely divided matter contained in the liquor was pulled thru the surface and then thru the filter. It was thought that if this should be a correct interpretation of the phenomenon, it might be obviated in one of two ways—by increasing the toughness of the surface deposit, or by decreasing the size of the sand pores by use of a layer of finer material on the surface. Both of these methods were tried.

To increase the density and toughness of the surface film the surface was covered with liquor, the outlet being closed, and 2 ounces of sulfate of aluminum were added and stirred in. Fifteen minutes were allowed for the formation and settling of the precipitate, and the filter was then started. The following data were obtained:

Data of test run of filter after addition of alum.

Duration of run	hours	1.9
Loss of head:		
Initial	inches	14
Final	do	55
Quantity filtered	gallons	370

The chemical analyses resulted as follows:

Analyses of raw liquor, of settled liquor, and of effluent after the addition of alum.

	Parts per million.	Per cent removed.
Raw liquor.		
Oxygen consumed:		
Total	9,000	.....
Dissolved	1,600	.....
Suspended	7,400	.....
Suspended solids	27,300	.....
Settled liquor.		
Oxygen consumed:		
Total	6,000	33
Dissolved	1,600	6
Suspended	4,400	40
Suspended solids	4,500	84
Effluent.		
Oxygen consumed:		
Total	1,800	80
Dissolved	1,600	0
Suspended	200	98
Suspended solids	450	98

The improvement of this effluent over that obtained without a coagulant is decided, but is hardly sufficient to warrant the extra cost of treatment. Previous studies had shown that it was necessary to add to the volume of waste on the surface of the filter at least 2 ounces of alum in order to bring about a satisfactory precipitation of the lime. Any less amount would not have produced a satisfactory precipitation in a short time. The total quantity filtered during the run was 370 gallons. This gives an amount of sulfate equal to a little over 2 grains per gallon for the entire run, or a consumption of 300 pounds of alum per million gallons. At a cost of 1 cent per pound (based on net weight of sulfate of aluminum in the crude compound) this would amount to $3 per million gallons of waste, or 10 cents per ton of finished board. This additional cost for chemicals, together with the slightly additional expenditure for labor and water required by more frequent washing, would not seem to be justified in general by the slightly increased purity of the effluent. The results are given here

and the cost estimated as a matter of record and in order to show what could be accomplished by the process if it were deemed desirable in any special case.

The second plan for preventing the small suspended particles in the liquor being drawn thru the surface was to use a surface layer of fine sand. A suitable grade of sand was obtained locally and screened thru a No. 20 screen. The sand thus prepared contained a considerable amount of rather fine materal. Mechanical analysis showed that it had an effective size of 0.26 mm. and a uniformity coefficient of 2.0.

A 6-inch layer of the sand was placed on the top of the filter and washt. After washing, the surface was examined and found to consist of a well-mixt layer of coarse and fine material. Two runs were made with the filter as thus prepared. The following are the average data obtained:

Data of test run of filter after addition of fine sand.

Duration of run	hours..	2.3
Loss of head:		
Initial	inches..	6
Final	do....	55
Quantity filtered	gallons..	449

The appearance of these effluents was such that chemical analyses were not made. They were essentially like the others, and there was no advantage in the use of the layer of fine sand which could in any way offset the obvious disadvantage of the much shorter run.

THE SLUDGE.

Amount and composition.—Thruout the experiments, except for the first few runs, the dirty wash water from the filter was run back into the sedimentation tanks. Eventually, therefore, all the material removed from the waste liquor was accumulated in the bottom of these tanks. At the conclusion of the experiments, which consisted altogether of 12 runs, dealing with a total of 4,900 gallons of the waste, the liquor was drawn off from the tanks as far as possible and the depth of accumulated sludge and remaining liquor was measured. The average depth was found to be 6 inches. After thoro mixing a sample of the sludge was collected and allowed to stand in a glass cylinder for two hours. From a column of sludge 12 inches in depth a 2-inch layer of clear liquid separated at the top, leaving the depth of sludge on the bottom 10 inches. Therefore the 6 inches of sludge and liquor left in the tank was composed of 5 inches of sludge and 1 inch of water, so that 5 inches represents very closely the average depth of sludge in each tank and will be used in the calculations which follow.

Analysis of the sludge gave the following results:

Analysis of sludge resulting from filtration of strawboard waste.

Specific gravity		1.094
Total solids	per cent	19.4
Volatile	do	9.8
Fixt	do	9.6

From these data the following results are obtained:

Sludge in tank	gallons	178
Liquor treated	do	4,900
Per cent of sludge (by volume)		1.6

From 1,000,000 gallons of waste there will be obtained—

Sludge	cubic yards	79
Dry solids	pounds	28,000
Organic solids	do	14,100
Mineral solids	do	13,900

For each ton of strawboard there will be produced—

Sludge	cubic yards	4.7
Dry solids	pounds	1,680

A glance at Pl. I, *B*, will indicate what these figures mean. The piles of straw there shown represent three months' supply for a mill producing 30 tons of board per day. Over one-third of the total weight of this straw will appear in the waste liquor.

Properties and uses of the sludge.—As is indicated by the analysis, the sludge is a thick mud. It is dark muddy brown in color, and has the odor of straw. On exposure to the air it dries much more rapidly than would be expected, owing largely to the action of the air on the free lime. If allowed to dry in a mold, the resulting cast comes away clear and has taken a very clean impression of the mold. It is very brittle by itself. If, however, a little paper fiber be mixt with it before drying, the dry cast is fairly tough. Such a mixture could undoubtedly be used in many places as a cheap substitute for papier-maché.

The dry product had a specific gravity of 0.62. It will readily absorb considerably more than its own weight of water. Its porous nature suggests its use as a heat insulator, particularly in refrigerators.

This material possesses a certain value as a fertilizer. It contains a considerable proportion of calcium carbonate, a substance beneficial to cultivated land. It also contains 0.34 per cent of phosphoric acid in an available form. Its loose, porous nature makes it particularly valuable for use on clay land, as such land is made much more porous by it and at the same time is sufficiently fine to retain the moisture well. This point was well brought out on examining one of the abandoned settling basins. This basin had originally been diked up about 6 feet

above the surrounding fields, and had subsequently been completely filled with the sludge. On digging into this deposit, standing water was observed at a depth of less than 2 feet below the surface, altho the ground-water level in the adjacent fields was at least 6 feet lower and the field had not been flooded for over a year.

Some experiments have been made with this solid residue as a base for the production of a sulfur dye. Fusion of the substance with twice its weight of a mixture of one part of sulfur and two of sodium sulfide yields a mass containing a considerable proportion, perhaps 20 per cent, of a brown sulfur dye. Purification of the resulting dye from the mass of inert material was not attempted, and further study is required to determine the most satisfactory procedure for the preparation and purification of this dye, but enough has been done to indicate that a low-grade sulfur dye can be made from this waste material. It dyes unmordanted cotton a good warm shade of brown, is fast to hot soap and to sunlight, and compares favorably in color and fastness with dyes on the market selling at 15 cents per pound.

Considerable attention has been given to the problem of finding profitable use for the residual organic matter which is the end product of the filtration processes here recommended. Altho the satisfactory solution of this problem would be highly desirable and would at once assure the treatment of all strawboard waste liquors, it must be remembered that this is merely a question incidental to the main problem. It is believed that the process of sedimentation, followed by mechanical filtration, essentially as described, furnishes by itself a solution of that problem which will prove of financial advantage to the manufacturers and of lasting benefit to all who have an interest in the purity of the streams below. It was therefore not deemed pertinent to the present investigation to pursue further the question of the utilization of the sludge. The suggestions here given, and particularly that in regard to the preparation of a dye, are merely intended to indicate the direction in which, according to the writer's views, future research would bring results of value.

RÉSUMÉ OF METHOD OF TREATMENT.

The following plan of treatment is recommended: The waste water from the beaters should be past thru a properly designed settling tank of such size that it will give a period of about one hour's storage. A tank built on the principle of the Dortmund tank would be preferable to any other, owing to its compactness and the possibility of continuous use. The tank should have a capacity of approximately 1,200 gallons for each ton of board produced per day by the mill.

The water should pass from the tank directly to the filters, which should be built in small units. The filters should have an available loss of head of at least 12 feet, and could be run at a rate of 100,000,000

gallons per acre per day. This would necessitate a filter area of approximately 16 square feet per ton of board produced daily. This figure allows 10 per cent excess for repairs and washing.

The effluent should be pumped and used again for washing the filter and for beater wash water. It would at all times contain less impurity than does the very last water past from the beaters and its use during the early part of the washing process could do no possible harm. To insure a proper washing out of the last of the lime from the stock it would probably be found necessary to complete the washing with fresh water. In any case a saving of one-half to two-thirds of the amount of wash water now used could be realized, the amount of waste liquor being correspondingly reduced. The water used in washing the filter should be returned to the sedimentation tank and would require no further treatment.

The sludge from the sedimentation tank could be most expeditiously dealt with by filter pressing. There would remain a fairly dry and hard press cake, which would require disposal unless some profitable use for it be found. Under the influence of the air and sun this material is speedily resolved into mineral matter, forming a sort of soil. It could be spread upon low land in thin layers and would then take care of itself.

Instead of being filter prest, the sludge might be discharged upon small areas of sandy soil where such are available or even upon somewhat larger areas of less porous soil, and allowed to dry out by draining and evaporation. The dry layer of sludge could then be removed and disposed of. No accumulation of the wet material should be allowed. When once dried out and subjected to the action of the sunlight and air it soon becomes harmless, but in deep beds and constantly covered with water it is subject to all the offensive putrefaction described in the case of the sedimentation fields. This process of spontaneous draining and drying out would probably be found the cheaper, but would require a considerable area of suitable land and would also involve more careful supervision. The amount of land required would depend wholly on the quality of the drainage. For average conditions it may be roughly estimated at 1,000 square feet per ton of board produced by the mill daily. The dried sludge would require removal before the application of more sludge.

CHARACTER OF WASTE WATER AFTER TREATMENT.

The quality of the effluent from the proposed process is not all that could be desired. In spite of the fact that it is possible to remove over 90 per cent of the suspended organic matter present in the liquor the resulting effluent is still putrescible. That is, a bottle of the liquor shut up air-tight and kept at a warm temperature will in the course of a few days undergo putrefactive fermentation. The putrefaction is

rather slow, however, and not offensive. In admixture with an e volume of tap water the effluent does not putrefy even when in lated with a small amount of sewage.

The fact that the effluent is practically free from gross suspe solids—that is, solids which will settle out on the bed of the strea of greater significance than the analytical data. As was pointe in the earlier discussion of the problem (p. 8), by far the gr part of the damage done to the polluted streams is brought abou the deposit of material in the stream beds. The effluent whic past the treatment here outlined will contain no material capab settling out even in slack water.

The conclusion is therefore justified that the discharge of this ef into a stream whose minimum flow equals in volume the flow the mill would not produce a nuisance. With no allowance possible diminution of the amount of wash water, if used as sugg above, this means that the minimum stream flow must be at leas cubic foot per second per ton of board produced daily at the mil minimum flow of 0.1 cubic foot per second per daily ton would t fore provide for a generous factor of safety if the stream is re ably unpolluted at the point of discharge.

The discharge of such an effluent into a stream highly polluted sewage would probably be accompanied by an aggravation of the ditions already existing. There would, as usual, be a precipitati the sewage material by the lime of the effluent. In all fairness it be maintained that the organic matter of the effluent was not contr ing to the nuisance. If, therefore, it should be decided that the tion of lime to a sewage-polluted stream constitutes a nuisance, fu treatment of the effluent would be required to remove this caustic If, on the other hand, as would seem to be reasonable, it should a that the real pollution of the stream lay in the sewage and the lim incidental and was there by right, there would be no reason for further treatment.

COST OF THE PROCESS.

The cost of the process recommended can not be discust in det this time. It would be largely the cost of installation. The d and construction of a suitable plant require expert attention an cost of the plant would depend somewhat on local conditions. Th of maintenance would be slight. The cost of additional pumpi supply wash water—say 5 per cent more than the present an pumped—can be determined readily. The services of one man, could also assist in the mill part of the time, would be a sufficient tion for running the plant. The power necessary to pump the sl thru the filter presses, if that plan were adopted, would not be n able in comparison with the total power used in the mill. If the sl

lisposed of by the other plan, evaporation and drying in the field, rvices of another man would be required.

conclusion, the following summary of the chief points of the ıt paper may be made:

SUMMARY.

present method employed for the treatment of strawboard waste that of sedimentation in large fields, is unsatisfactory and ive and proceeds on a wrong principle.

filtration of the liquor thru sand, so-called mechanical filtration, thout coagulants, after a short period of sedimentation will 93 per cent of the suspended organic solids and 98 per cent of ıl suspended matter determined as turbidity.

al experiments have shown that the resulting effluent can be ged into an equal volume of reasonably pure water without g a nuisance. In particular, there will be no sedimentation ınic matter. If its discharge into a seriously polluted stream bring about precipitation of sewage matter and consequent e, the blame should in all equity be fixt on those contributing 'age.

sludge resulting from the sedimentation tanks, after pressing or ıeous drying, is innocuous and makes good soil. It has some s a fertilizer and is particularly valuable to mix with the clay the Middle West to render them more porous. Other uses for ıterial are suggested, but they require further study.

cost of the entire process is sufficiently low to admit of its adop- herever stream pollution is serious.

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[Water-Supply Paper No. 189.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

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SERIES L, QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)

WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)

WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.

WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.

WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp., 15 pls.

WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.

WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.

WS 113. Strawboard and oil wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.

WS 121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.

WS 144. The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.

WS 151. Field assay of water, by M. O. Leighton. 1905. 77 pp., 4 pls.

WS 152. A review of the laws forbidding pollution of inland waters in the United States, second edition, by E. B. Goodell. 1905. 149 pp.

WS 161. Quality of water in upper Ohio River basin and at Erie, Pa., by S. J. Lewis. 1906. 114 pp 6 pls.

WS 179. Prevention of stream pollution by distillery refuse, based on investigations at Lynchbur Ohio, by Herman Stabler. 1906. 34 pp., 1 pl.

WS 185. Investigations on the purification of Boston sewage, by C. E. A. Winslow and Earle Phelps. 1906. — pp.

WS. 186. Stream pollution by acid-iron wastes, a report based on investigations made at Shelby, Ohi by Herman Stabler. 1906. 36 pp., 1 pl.

WS. 189. The prevention of stream pollution by strawboard waste, by Earle Bernard Phelps. 190 29 pp., 2 pls.

Correspondence should be addrest to

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Water-Supply and Irrigation Paper No. 190 Series 0, Underground Waters, 67

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CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS OF COASTAL PLAIN OF TEXAS

BY
THOMAS U. TAYLOR

WASHINGTON
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ILLUSTRATIONS.

Pl
PLATE I. *A*, A typical artesian well in the Texas Coastal Plain; *B*, Artesian well 4 miles south of Pearsall, Tex
II. Map showing location of artesian wells in the Texas Coastal Plain...
III. Artesian wells in Rio Grande embayment

A. A TYPICAL ARTESIAN WELL IN THE TEXAS COASTAL PLAIN.

B. ARTESIAN WELL A [illegible]

UNDERGROUND WATERS OF THE COASTAL PLAIN OF TEXAS.

By T. U. Taylor.

INTRODUCTION.

Area covered.—The region to which this report relates includes the greater part of the Coastal Plain of Texas. It comprises an area about 150 miles wide, bordering the coast and extending across the entire State. According to R. T. Hill's classification it includes the "eastern" and "southern" provinces, and it is bordered on the west, from Del Rio to Colorado River, by the "Edwards Plateau," and, from the Colorado River to the Arkansas State line, by the "Black Prairie." It includes the district lying between the coast and a line connecting Texarkana with Del Rio, through Cooper, Greenville, Corsicana, Cameron, Elgin, and San Antonio, an area of about 75,000 square miles.

Sources of data.—The information on which this report is based has been obtained partly by personal visits to the various localities and partly by correspondence. Information has been furnished by the following persons: B. M. Haberer, C. F. H. von Blucher, Randolph Robertson, F. W. Simonds, H. W. Harper, Ira H. Evans, Rudolph Kleberg, T. J. Lyne, G. Warnicke, R. D. Parker, O. M. Ball, Garland Miller, A. W. Seeligson, J. B. Armstrong, J. L. Ladd, Travis L. Smith, E. D. Dorchester, Geo. C. Herman, Geo. J. McManus, J. E. Broussard, and J. W. Sanders. The writer is also indebted to Mr. E. T. Dumble, former State geologist of Texas, for much valuable information.

GEOGRAPHY OF THE REGION.

General statement.—The Coastal Plain of Texas is a continuation of the Atlantic Coastal Plain to the east, although in many features it differs from that area. In general it consists of a gently sloping plain, extending from a high or mountainous background to the Gulf. In the eastern part of Texas the Coastal Plain has the general character seen in other Southern States, but in its southwestern extension it becomes more or less modified, widening to the southwest in the

vicinity of the Rio Grande where there is a great embayment sin to that of Mississippi River. South of Colorado River there is a v defined interior border to the Coastal Plain, but to the north of stream the transition between the level and hilly lands is gradua

Topography.—The topography of the Texas Coastal Plain pres little variety. The surface rises gradually from the sea level at coast to an elevation of 800 to 1,000 feet along the interior margi the province. The portion of the plain bordering the coast is c acterized by a very level surface which, throughout extensive area scarcely broken, except by a few shallow drainage ways. The high land along the coast is at Corpus Christi, where the bluffs rise to 40 t feet above sea level. Toward the interior the surface of the p becomes more diversified, developing into rolling hills which incr in number and prominence toward the western margin of the provi

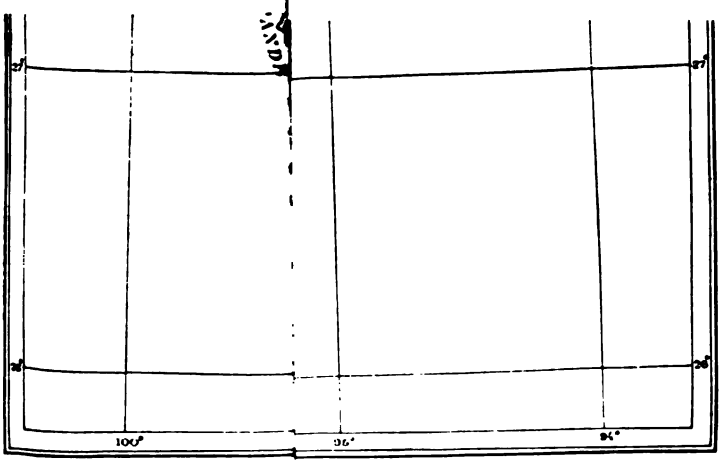
Drainage.—The Texas Coastal Plain is traversed by many strea The largest of these are the Neches, Trinity, Brazos, Colorado, Nueces rivers. Of all these streams only the Brazos enters the directly, the others emptying into lagoons or bays. South of Nueces the drainage is not completely developed and the entire a between this stream and the Rio Grande contains only two sm creeks, the San Fernando and Olmos, which unite to form Cap Bay. The larger streams of the area are generally narrow and d with feeble currents. Near the shore many of them expand i broad, shallow lakes entering the Gulf through shallow bays. W there are many streams in the Texas Coastal Plain, much of its surf is poorly drained, and in places water stands in lakes or ponds throu out the year.

GEOLOGY.

The Texas Coastal Plain is developed on a great thickness of rocks, sands, gravel, clays, and loams in general spread in thin more or less extensive beds which dip very gently to the east. Th sediments have a thickness of several thousand feet and are comp of alternating porous and impervious members, producing i artesian conditions. Over the greater part of the area the rocks of Tertiary age, but along the interior border Upper Cretaceous s ments appear.

UNDERGROUND WATERS, BY COUNTIES.

General statement.—During recent years the underground-w resources of the Texas Coastal Plain have become of consider economic importance. Ground water, which is usually abund throughout the district, has been used for many years for gen domestic purposes, and small irrigation plants in a few instances h derived their water supply from this source. Within recent y


37°
37°
30°
30°
100°
96°
94°

artesian wells have been obtained in various parts of the region. Some of these furnish flows adequate for considerable irrigation. Three of the larger cities in the region, Houston, Galveston, and San Antonio, derive their entire city water supply from artesian sources. At Houston the city water is supplied by 60 flowing wells, while at Galveston and San Antonio 15 and 30 wells, respectively, furnish the required amounts. In the vicinity of El Campo, Chesterville, and East Bernard shallow artesian wells are employed to a considerable extent for rice irrigation, especially where small crops are raised. In the vicinity of Webster, in the southern part of Harris County, the flow of several ordinary surface wells has been increased, by pumping, to such an extent as to furnish water for the irrigation of 60 to 100 acres of rice. The depth at which artesian water may be obtained in the Coastal Plain of Texas varies according to the locality. It ranges from a few feet to over 2,000 feet, but the average is about 600 feet.

The amount of flow of these wells varies from 20 to 1,600 gallons a minute. A typical artesian well of this district is shown in Pl. I. The water is more or less mineralized, but with few exceptions the dissolved salts are neither objectionable for domestic purposes nor deleterious to plant growth. The general distribution of artesian wells of the Coastal Plain of Texas is shown in Pl. II.

In the following discussion the underground-water resources of the region will be described by counties.

CAMERON COUNTY.

Shallow wells.—The depths of the shallow wells of Cameron County vary from 20 to 100 feet, according to the locality. Along the coast water can usually be procured at depths of 20 to 30 feet, but, owing to the nearness of the sea, it is generally salty. To the north, along the bay, the wells are somewhat deeper, ranging from 20 to 60 feet, and in the western part of the county the deepest wells occur, some exceeding 100 feet. At Brownsville and in the immediate vicinity the average depth of shallow wells is about 30 feet.

Artesian wells.—Artesian water is now obtained in the northern two-thirds of this county, at depths which vary from 600 to 1,200 feet. There are about 150 flowing wells in the county. The flows of these wells vary from 50 to 1,000 gallons a minute, the average being about 300 gallons. A group of artesian wells in the Rio Grande embayment is shown in Pl. III (p. 6). The following is a list of artesian wells in Cameron County:

Artesian wells in Cameron County.

THE KENEDY PASTURE COMPANY'S WELLS.

Name.	Driller.	Depth.	Flo mit
		Feet.	*Gal*
La Parra	Wm. Turcotte	710	
Do	do	825	
Do	do	890	
San Juan	do	1,000	
Abujon	do	1,030	
Moyote	do	610	
Sacahuista!	do	998	
Eurebia	do	920	
Shipping pasture	do	689	
Devisadero	do	724	
Cobos	do	645	
Paistle	do	710	
Salada	do	700	
Corte Sacate	do	751	
Mota del Diablo	do	1,019	
Atravesada	Guffey & Galey	720	
Alto	do	1,120	
Casa Mott	White Bros	1,175	
Palmito	W. P. Gano	1,035	
Ramirez	do	1,123	
Edwin Mallory	do	1,170	
Padre Alejos	N. G. Allen	865	
Sarita	Railroad	604	
Mifflin	Town site	740	
Turcotte	do	787	
Snipe	Wm. Turcotte	620	
Esperanza	do	747	
Barasas	do	700	
El Suspiro	do	615	
La Saragote	do	652	
Mujeres	do	660	
Mesquite de Final	do	750	
Paradiso	do	917	
Tio Coulas	do	892	
Tecolite	N. G. Allen	890	
Motto Negra	Wm. Turcotte	1,080	
Perez	Tom Leary	1,360	
Agua Negra	W. P. Gano	1,125	
Mentidua	do	1,033	
Mestana	do	1,232	
El Toro	Wm. Turcotte	1,025	
Repara	do	1,130	
Mayote, No. 2	W. P. Gano	1,147	
San Juan, No. 2	Wm. Turcotte	890	
Tio Martin	do	860	
Picacho, No. 2	do	1,155	
Mesquite	do	750	
La Serpa	do	617	
Miralejos	do	862	
Los Mojaras	do	760	
Picacho, No. 1	Tom Leary	1,403	
No name	do	1,314	
La Piedra	Wm. Turcotte	950	
La Tablome	do	1,000	
Motta Palle	do	(a)	....
Motta Romendonda	do	814	
Townsite, No. 1	W. P. Gano	807	
Townsite, No. 2	do	818	
Medeneta	do	1,315	
La Muerta	do	843	
Bordos	Wm. Turcotte	862	
Gansos, No. 1	W. P. Gano	1,234	
Gansos, No. 2		(a)	....
El Telephon	Wm. Turcotte	951	
Railroad (new track)	W. P. Gano	803	
Loma Prieta	Wm. Turcotte	(a)	....
Courta Sacate	do	757	

a In progress.

Artesian wells in Cameron County—Continued.

LOWER KING RANCH.

Name.	Driller.	Depth.	Flow per minute.
		Feet.	*Gallons.*
	A. W. Ferguson	530	70
	do	682	12
	do	747	200
	do	382	75
	do	668	35
	do	1,364	60
	J. C. Curry	851	300
	do	838	300
	do	719	50

MAJ. J. B. ARMSTRONG'S WELLS.

	Sanders & Allen	490	20
	do	500	20
	Thos. Fowler	830	150
	Curry & Sons	770	75
	J. B. Armstrong	568	.....
	R. Robertson	730	60
	J. C. Curry	805	100
	do	857	150
	do	830	108
	do	780	160
	J. B. Armstrong	893	150
	do	(a)	.....

a In progress.

Record of Atravesada well, on Kenedy ranch, Cameron County.

	Feet.
soil	0 – 1½
sand, salty	1½ – 10
sand	10 – 35
water seep	35 – 45
lay and bowlders	45 – 50
nd bowlders	50 – 80
ted shells	80 – 82
	82 – 90
nd bowlders	90 –100
ted shells	100 –103
owlders	103 –110
nd brown clay	110 –140
to buff clay	140 –265
ted shells, scallop shaped	265 –320
to buff clay	320 –330
nd rock	330 –335
and rock	335 –360
clay	360 –380
ock	380 –380½
	380½–400
ock	400 –400½
	400½–420
	420 –422
	422 –440
	440 –440½
ained bluish rock	440½ 460
rownish clay	460 470
brown clay and sand	470 –555
	555 –615

	Feet
Very hard gumbo	615–
Reddish gumbo	640–
Rock	694–
Clay	696–
Water-bearing sand; strong flow	700–
Red clay	720–
Hard red clay	765–

Record of well at Sauz ranch, Cameron County.

	Feet
Pale-red, sandy clay	0–
Sand	15–
Very pale-red clay, sandy	30–
Sand containing hard layers	50–
Sand with very soft blue clay	250–
Sand and bluish clay	315–
Sandstone	500–
Yellow sand	512–
Sandstone	517–
Sand	525–
Very hard bluish rock	529–
Rock and clay	699–
Red and blue clay with hard layers	729–
Bluish clay with red layers	899–
Reddish and greenish clay	989–1.
Sand	1,099–1.

Record of Orejas well, 8 miles east of Sauz ranch, Cameron County.

	Feet
Soil and clay	0–
Sand and clay	10–
Clay and sand in hard and soft layers	53–
Sand	68–
White clay and gravels ("Equus beds")	81–
Sandy clay and sand rock	115
Sand and sandstone	134–
Clay and sandstone	185–
Sand	208–
Blue clay	225–
Sand	278–
Sand and sandstone	290–
Blue clay	378–
Coarse sand	408–
Clay containing hard layers	421–
Sandstone	442–
Sand	450–
White clay	470–
Sand	476–
Bluish clay	490–
Sand and sandstone	520–
Bluish clay	532–
Sand and sandstone	551
Blue clay	560–
Sandy clay	585
Very fine sand	596–
Sand and sandstone	613–

ARTESIAN WELLS IN RIO GRANDE EMBAYMENT

	Feet.	
Very hard gumbo	615–	640
Reddish gumbo	640–	694
Rock	694–	696
Clay	696–	700
Water-bearing sand; strong flow	700–	720
Red clay	720–	765
Hard red clay	765–	800

Record of well at Sauz ranch, Cameron County.

	Feet.	
Pale-red, sandy clay	0–	15
Sand	15–	30
Very pale-red clay, sandy	30–	50
Sand containing hard layers	50–	250
Sand with very soft blue clay	250–	315
Sand and bluish clay	315–	500
Sandstone	500–	512
Yellow sand	512–	517
Sandstone	517–	525
Sand	525–	529
Very hard bluish rock	529–	699
Rock and clay	699–	729
Red and blue clay with hard layers	729–	899
Bluish clay with red layers	899–	989
Reddish and greenish clay	989–	1,099
Sand	1,099–	1,104

Record of Orejas well, 8 miles east of Sauz ranch, Cameron County.

	Feet.	
Soil and clay	0–	10
Sand and clay	10–	53
Clay and sand in hard and soft layers	53–	68
Sand	68–	81
White clay and gravels ("Equus beds")	81	115
Sandy clay and sand rock	115–	134
Sand and sandstone	134–	185
Clay and sandstone	185–	208
Sand	208–	225
Blue clay	225–	278
Sand	278–	290
Sand and sandstone	290–	378
Blue clay	378–	408
Coarse sand	408–	421
Clay containing hard layers	421–	442
Sandstone	442–	450
Sand	450–	470
White clay	470–	476
Sand	476–	490
Bluish clay	490	520
Sand and sandstone	520–	532
Bluish clay	532	551
Sand and sandstone	551–	560
Blue clay	560–	585
Sandy clay	585–	596
Very fine sand	596–	613
Sand and sandstone	613	630

ARTESIAN WELLS IN RIO GRANDE EMBAYMENT.

HIDALGO COUNTY.

Shallow wells.—Water is procured from wells in Hidalgo County at depths varying from 25 feet on the lower ground to 150 feet on the highlands. An abundant supply is usually obtained.

Artesian wells.—During the last few years many successful artesian wells have been bored in the northern half of Hidalgo County. These are located mainly on the Lasater, Sullivan, Armstrong, Ward & Russell, and King ranches. In January, 1906, information had been obtained of about 60 of these wells, but there are others about which no data are available. The following is a partial list of the wells, giving their depth and approximate flow.

Artesian wells in northern Hidalgo County.

ED. C. LASATER RANCH.

Name.	Driller.	Depth.	Flow per minute.
		Feet.	*Gallons.*
No. 9	O. S. Caldwell	460	10
No. 4	do	438	35
Realitos	Perry Downs	478	75
White Sulphur	do	484	75
Patricio	do	460	25

D. SULLIVAN RANCH.

Jap Twins	S. A. Hamlin	742	400
Do	do	1,008	600
Three-fourths mile	do	820	800
Tula Twin	do	630	300
Do	do	630	400
Olmos Creek	do	350	500
South Twin	do	530	200
Do	do	530	150

WARD & RUSSELL RANCH.

No. 1	S. A. Hamlin	±500	Flows.
No. 2	do	±500	Do.
No. 3	do	±500	Do.
No. 4	do	1,008	Do.

KING RANCH.

Gigante	A. W. Ferguson	382	75
Andrea	do	530	70
Mesquitine	do		
Tampico	do	719	50
Comanche	do	668	35
Lesaca	do	747	200

A chemical analysis of the water of the White Sulphur well (Lasater ranch) is given below:

Analysis of water from White Sulphur well, Lasater ranch, Hidalgo County.[a]

	Parts per million.		Parts per million.
Ammonium (NH_4)	0.04	Total solids at 105°	1,090.00
Sodium (Na)	260.00	Total solids ignited, dull redness	1,000.00
Magnesium (Mg)	29.00	Loss on ignition	90.00
Calcium (Ca)	75.00	Albuminoid ammonia (NH_3)	.01
Iron (Fe)	2.60	Free ammonia (NH_3)	.023
Chlorine (Cl)	380.00	Nitrites	.007
Nitrate radicle (NO_3)	.02	Oxygen required	4.500
Sulphate radicle (SO_4)	170.00	Temporary hardness	140.00
Bicarbonate radicle (HCO_3)	120.00	Permanent hardness	68.00
Silica (SiO_2)	36.00		
Organic matter	12.00		
	1,084.66		

STARR COUNTY.

Shallow wells.—Water is generally obtained at shallow depths throughout Starr County, but along the Rio Grande a large portion of the inhabitants use river water.

Artesian wells.—Artesian water is found in the northeastern part of the county, near the town of Falfurrias. The wells range in depth from 540 to 1,020 feet. In the deeper borings five distinct water horizons are encountered, some of which have a capacity of 250 gallons a minute. The water is used extensively for irrigation, and during the last two years the progress in artesian irrigation has been very rapid. The following is a list of wells in Starr County:

Artesian wells in Starr County.

Name.	Depth.	Flow per minute.	Name.	Depth.	Flow per minute.
	Feet.	*Gallons.*		*Feet.*	*Gallons.*
Los Mosquitos	710	25	Colosa	669	100
Mesquite	540	100	Railroad	810	150
Alto Bonito	562	250	Tank	756	100
Barendo	526	30	Falfurrias No. 2	1,020	80
Copa	603	30	Falfurrias No. 3	700	110
Falfurrias No. 1	800	15	Copita	664	75
Novilla	760	75			

[a] Analysis by H. W. Harper and B. C. Glascock, school of chemistry, University of Texas, Austin April, 1903.

An analysis of the water from the Mesquite well is given below:

Analysis of water from Mesquite well, Lasater ranch, Starr County.[a]

	Parts per million.		Parts per million.
Ammonium (NH_4)	0.07	Total solids at 105°	680
Sodium (Na)	170.00	Total solids ignited, dull redness.	610
Magnesium (Mg)	.3	Loss on ignition	70
Calcium (Ca)	38.00	Albuminoid ammonia (NH_3)	.062
Iron (Fe)	.1	Free ammonia (NH_3)	.006
Chlorine (Cl)	.4	Oxygen required	16
Nitrate radicle (NO_3)	None.	Temporary hardness	230
Sulphate radicle (SO_4)	39.00	Permanent hardness	19
Bicarbonate radicle (HCO_3)	150.00		
Silica (SiO_2)	18.00		
Organic matter	44.00		
	459.87		

NUECES COUNTY.

Shallow wells.—At most places throughout Nueces County water can be obtained at depths of 30 to 40 feet, but in the southern part of the county many of the shallow wells furnish brackish water. There are wells in the northern part of the county which range in depth from 50 to 180 feet. The deepest of these penetrated a water-bearing sand which furnishes 60 gallons of water a minute. Throughout the eastern part of the county water is obtained at a depth of 35 to 40 feet, but much of it is saline. Along the west side of the county the wells 80 feet deep supply only a small amount of water, while those which have been bored to a depth of 150 feet afford an abundance, and in many of them the water rises to within 70 feet of the surface.

Artesian wells.—Artesian water is secured throughout the southern two-thirds of this county at depths which vary from 490 to 1,240 feet. In the amount of flow these wells range from a few gallons to over 600 gallons a minute. So far no flowing wells have been obtained north of the Texas and Mexico Railroad, although borings have been made at Alice, Robstown, and Corpus Christi. The northernmost of the successful wells in this county are on the Driscoll ranch. A list of the artesian wells, giving their depth, flow, and other data, follows.

[a] Analysis by H. W. Harper and C. Hartmann, school of chemistry, University of Texas, Austin, April, 1903.

Artesian wells in Nueces County.

KING'S WELLS.

Name.	Driller.	Depth.	Flow mini
		Feet.	*Gallo*
Palo Alto No. 1	T. Herring	552	
Palo Alto No. 2	do	704	
Santa Gertrudis No. 1	do	535	
Parrita	do	470	
Ebanito No. 1	do	456	
Ebanito No. 2	do	475	
Fitch	do	396	
Jenson	do	402	
Baltimore	do	474	
Canelo	do	495	
Oaso Ancho	do	590	
Lower Little Pasture	do	545	
Santa Gertrudis No. 2	do	550	
Coyote	do	795	
Chiltipin	do	840	
Burro	do	928	
Telephone	do	874	
Portales	do	1,085	
Guayacan	do	905	
Jaboncillos	do	948	
Rincon de Los Cabellos	King Machinery Co.	764	
Bovida	do	720	
Retamosa	do	447	
Conchas	do	427	
Vivoras	do	989	
Visnaga	do	913	
Santa Gertrudis No. 3	A. W. Ferguson	565	
Santa Gertrudis No. 4	do	560	
Alazan	do	423	
Santa Clara	do	525	
Valederas	Tom Leary	591	
Rincon de Tio Pancho	do	615	
Leoncitas	do	570	
Tranquitas	do	655	
Little Pasture	do	574	
Rediche	do	680	
Tranquecitos	do	640	
Caldwell	do	540	
Indios	do	480	
Mota Negra	do	550	
Palo Marcado	do	700	
Comitas	do	578	
Homer	A. B. Fuller	506	
Alazan No. 2	King Machinery Co.	465	
Cobeza	do	410	
Priesta	do	635	
Ebenito	do	397	
Leoncitas No. 2	do	1,050	
Herring	T. Herring	805	
Young	J. P. Morris	630	
Taylor	T. Herring	620	
Johnson	J. P. Morris	626	
Reed	T. Herring	616	
Harper	R. J. Mills	625	
Kingsville	R. Robertson	609	
Simms	W. J. House	600	
McNeil	T. Herring	610	
Warren	A. B. Fuller	628	
Huffman	T. Herring	630	
Jesse	J. P. Morris	640	.....
Weir	W. J. House	(a)	.....
Harvey	T. Herring	632	
Hoffman	do	626	
Alexander	do	.....	.....
Penn	W. J. House	650	
Santa Gertrudis No. 5	King Machinery Co.	580	

a In progress.

Artesian wells in Nueces County—Continued.

SEELIGSON'S WELLS.

Name.	Driller.	Depth.	Flow per minute.
		Feet.	*Gallons.*
.....	C. Premont.....	464	50
.....	....do.....	633	65
anch.....	....do.....	630	8
.....	....do.....	475	75

ANNA COLLINS'S WELLS.

.....	White Bros.....	625	50
.....	....do.....	825	9
.....	....do.....	918	150
.....	....do.....	790	50

ROBERT DRISCOLL'S WELLS.

o.....	Chas. P. Fox.....	612	150
.....	....do.....	653	100
.....	Leary & Gano.....	525	25
.....	Thos. Fowler.....	.....	60
.....	....do.....	.....	100

ANDRES CANALES'S WELLS.

.....	F. Rosales.....	440	80
.....	....do.....	458	80

CHARLES WEIL'S WELL.

l.....	Leary & Gano.....	558	35

RAGLAND & HERRING'S WELLS.

l.....	T. Herring.....	470	100
.....	W. C. Downing.....	499	60

EXAS LAND AND CATTLE COMPANY'S LAURELES RANCH WELLS.

sture.....	O. S. Caldwell.....	1,130	40
.....	....do.....	926	30
.....	....do.....	1,068	160
alle.....	J. McAlester.....	1,020	120
alle.....	....do.....	1,240	240
.....	....do.....	1,150	25
alle.....	....do.....	1,185	60
rs.....	....do.....	998	80
alle.....	....do.....	1,295	35

Artesian wells in Refugio County.

Owner.	Depth.	Flow per minute.	Distance and direction from Anaqua.
	Feet.	*Gallons.*	
O'Connor	946	60	7.5 miles south, 5 miles we
Do	826	175	14 miles south, 15 miles we
Do	1,204	175	11.5 miles south, 25 mi west.
Do	972	150	13 miles south, 5 miles ea
Do	1,000	40	19 miles south, 8 miles ea

ARANSAS COUNTY.

Shallow wells.—In Aransas County, which borders the coast, wa is obtained at depths varying from 25 to 80 feet.

Artesian wells.—There are at present no artesian wells in this cou and as far as can be ascertained no prospecting has been done.

CALHOUN COUNTY.

Shallow wells.—The average depth of shallow wells through Calhoun County is 30 feet, and in most cases an abundant suppl obtained.

Artesian wells.—There are 21 artesian wells in Calhoun Cou mainly on the ranch of T. M. O'Connor. Their approximate locat together with other data, is given in the following table:

Artesian wells in Calhoun County.

Owner.	Depth.	Flow per minute.	Distance and di from Point La
	Feet.	*Gallons.*	
C. A. Mitchell [a]	380	Weak.	4 miles northe
J. E. Shutt [b]	802	63	
H. C. Clark	496	12	8 miles southe
Do	330	8	8 miles south.
Do	360		Do.
Thomas estate	441	4	4 miles south.
Do	442	6	5 miles south.
Do	500	9	7 miles southw
J. B. Watkins	366		9 miles south.
T. M. O'Connor:			
Oil	780		14 miles southea
Boggy	572		16 miles southea
Old pens	570		14 miles southea
Johnny Woods	600		12 miles southea
Double dams	540		Do.
Cein Pond	490		14 miles southea
Eclipse No. 1	480		Do.
Queen	482		15 miles southea
Branding pen	460		13 miles southea
Perry Bend	480		11 miles southea
Eclipse No. 2	316		12 miles southea
Tule Pond	315		10 miles south.
Eclipse No. 3	320		11 miles south.
Bayshore Dandy	390		15 miles south.
Eagle Nest	460		Do.
Alligator	1,484		16 miles south.
Dugan dam	280		17 miles south.
Salt flat	275		18 miles south.
Middle Dandy	420		15 miles south.
Fence line	480		14 miles south.
25-foot Dandy	480		Do.

[a] Diameter 1¼ inches. [b] Diameter 2 inches.

Record of well at Alligator Head, Calhoun County.[a]

	Feet.	
Surface soil	0–	3
Fine white quicksand	3–	21
White clay	21–	43
Greenish clay containing shells	43–	80
Gray sand	80–	83
Hard yellowish clay	83–	160
Coarse sand containing shells	160–	166
Hard clay containing shells	166–	210
Sand	210–	225
Hard clay containing oyster shells	225–	320
Sand containing oyster shells	320–	365
Blue clay containing a few shells	365–	452
Coarse gray sand	452–	476
Conglomerate	476–	551
Gray sand	551–	567
Conglomerate with layers of blue clay	567–	694
Gray sand, traces of oil	694–	704
Hard rock	704–	707
Light sand, traces of oil	707–	710
Blue clay	710–	713
Hard rock with soft layers	713–	725
Gray sand containing fragments of shells	725–	767
"Shell concrete"	767–	887
Sand, water and oil bearing	887–	912
Conglomerate	912–	916
Gray sand	916–	942
Blue clay containing bowlders and shells	942–	1,008
Light-colored clay and fine gray sand in alternate layers	1,008–	1,022
Blue clay	1,022–	1,039
Rock	1,039–	1,042
Blue clay containing bowlders and shells	1,042–	1,051
White sand, traces of oil	1,051–	1,052
Blue clay with hard layers	1,052–	1,056
Light-colored clay with hard layers	1,056–	1,087
White sand, water bearing	1,087–	1,097
Red and blue clay	1,097–	1,230
Light-colored clay iron stained	1,230–	1,462
Variegated clay	1,462–	1,484

VICTORIA COUNTY.

Shallow wells.—Shallow wells are obtained in Victoria County at depths varying from 30 feet in the southern part to 80 feet in the northern and western parts.

Artesian wells.—Information has been received of 17 artesian wells in this county. The majority of these wells are on the Keeran ranch in the watershed of Garcitas and Aranosa creeks. The following is a list giving their depth, flow, diameter, and approximate location:

[a] Furnished by J. D. Mitchell, Victoria, Tex.

Artesian wells in Refugio County.

Owner.	Depth.	Flow per minute.	Distance and direction fro Anaqua.
	Feet.	*Gallons.*	
O'Connor	946	60	7.5 miles south, 5 miles we
Do	826	175	14 miles south, 15 miles we
Do	1,204	175	11.5 miles south, 25 mi west.
Do	972	150	13 miles south, 5 miles eas
Do	1,000	40	19 miles south, 8 miles eas

ARANSAS COUNTY.

Shallow wells.—In Aransas County, which borders the coast, wat is obtained at depths varying from 25 to 80 feet.

Artesian wells.—There are at present no artesian wells in this count and as far as can be ascertained no prospecting has been done.

CALHOUN COUNTY.

Shallow wells.—The average depth of shallow wells throughou Calhoun County is 30 feet, and in most cases an abundant supply obtained.

Artesian wells.—There are 21 artesian wells in Calhoun Count mainly on the ranch of T. M. O'Connor. Their approximate locatio together with other data, is given in the following table:

Artesian wells in Calhoun County.

Owner.	Depth.	Flow per minute.	Distance and directi from Point Lavaca
	Feet.	*Gallons.*	
C. A. Mitchell [a]	380	Weak.	4 miles northeast.
J. E. Shutt [b]	802	63	
H. C. Clark	496	12	8 miles southeast.
Do	330	8	8 miles south.
Do	360	.....	Do.
Thomas estate	441	4	4 miles south.
Do	442	6	5 miles south.
Do	500	9	7 miles southwest.
J. B. Watkins	366	.....	9 miles south.
T. M. O'Connor:			
Oil	780	.....	14 miles southeast.
Boggy	572	.....	16 miles southeast.
Old pens	570	.....	14 miles southeast.
Johnny Woods	600	.....	12 miles southeast.
Double dams	540	.....	Do.
Cein Pond	490	.....	14 miles southeast.
Eclipse No. 1	480	.....	Do.
Queen	482	.....	15 miles southeast.
Branding pen	460	.....	13 miles southeast.
Perry Bend	480	.....	11 miles southeast,
Eclipse No. 2	316	.....	12 miles southeast
Tule Pond	315	.....	10 miles south.
Eclipse No. 3	320	.....	11 miles south.
Bayshore Dandy	390	.....	15 miles south.
Eagle Nest	460	.....	Do.
Alligator	1,484	.....	16 miles south.
Dugan dam	280	.....	17 miles south.
Salt flat	275	.....	18 miles south.
Middle Dandy	420	.....	15 miles south.
Fence line	480	.....	14 miles south.
27-foot Dandy	480	.....	Do.

[a] Diameter 1½ inches

[b] Diameter 2 inches.

A well owned by S. H. Beasley, drilled in 1903 close to the west bank of Navidad River, about 1 mile north of the crossing of the New York, Texas and Mexican Railway, has the following record:

Record of Beasley well in central Jackson County.

	Feet.
Sandy soil	0 – ½
Red clay	½– 16
Red sand	16 – 30
Red clay	30 – 46
Rock	46 – 47
Sand	47 – 55
Rock	55 – 56
Sand and red clay in alternate layers	56 –120
Sand	120 –140
Rock	140 –141
Sand	141 –223
Red clay and sand	223 –249
Rock	249 –258½
Clay and rock	258½–268½
Red clay	268½–270½
Sand	270½–285½
Rock	285½–286
Red clay	286 –287
Sand	287 –289
Rock	289 –290
Sand	290 –311
Rock	311 –335½
White clay	335½–339
Sand	339 –361
Rock	361 –387½
Sand	387½–408½
Rock	408½–411
Sand	411 –414
Rock	414 –424
Sand	424 –465
Rock	465 –469
Sand	469 –479
Rock	479 –481
Sand	481 –498
Rock	498 –510
Sand	510 –521
Rock	521 –525
Sand	525 –545
Red clay	545 –548
Sand	548 –558
Red clay	558 –566
Sand	566 –586
Rock	586 –596
Sand	596 –640
Blue clay	640 –650
Sand and clay in alternate layers	650 –665
Rock	665 –669
Sand	669 –675

Artesian wells in Victoria County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
Rathbone & Weeder	1,045	90	.....	City of Victoria.
J. N. Keeran	180	Flows.	.....	Southeast of Victoria.
Do	200	Flows.	.....	Do.
Do	148	Flows.	.....	Do.
Do	705	Flows.	.....	Do.
Do	130	Flows.	.....	Do.
Do	77	Flows.	.....	Do.
Do	50	Flows.	.....	Do.
Do	222	Flows.	.....	Do.
Do	110	Flows.	.....	Do.
Do	140	Flows.	.....	Do.
Do	425	Flows.	.....	Do.
Do	180	Flows.	.....	Do.
A. M. McFadden	716	10	2	Kemper, 1.5 miles south.
Do	592	10	3	Kemper, 1.7 miles south.
Ross Clark	152	50	2	Kemper, 7 miles north.
Jno. T. Rusk	226	00	.....	Inez, 7 miles north.

JACKSON COUNTY.

Shallow wells.—Water is obtained in the eastern part of Jackson County at depths varying from 25 to 40 feet; in the southern and western parts from 40 to 60 feet; and in the northern part from 25 to 45 feet.

Artesian wells.—Artesian water has been found in this county south of the New York, Texas, and Mexican Railway, and it is believed by local observers that artesian water can be obtained almost anywhere in the northern part of the county. The following table gives a list of the wells, with their depth, flow, and approximate location.

Artesian wells in Jackson County.

Owner.	Depth.	Flow per minute.	Location.
	Feet.	*Gallons.*	
C. Branch	223	7	Edna, 10 miles southeast.
Do	365	5	Do.
H. Bowers	360	42	Edna, 16 miles southeast.
S. Mitchell	402	4	Edna, 25 miles southeast.
R. Clement	398	2	Edna, 14 miles southeast.
W. Westhoff	785	6	
Buhler	325	.....	
L. Ward	324	.....	
A. W. Lewis	362	150	Carancohue, 2 miles east.
R. E. Ward	330	60	Carancohue, 3 miles east.
Do	338	100	Carancohue, 7 miles south.
Do	348	40	Carancohue, 10 miles southeast.
Do	366	100	Carancohue, 6 miles east.
Do	401	50	Carancohue, 5 miles southwest.
Thos. Dewees	893	.....	
Do	777	.....	
Do	540	.....	
Bennett & West	360	.....	
Do	152	.....	
Do	560	.....	
Do	240	.....	
Do	480	.....	
Do	355	.....	
Do	450	.....	

A well owned by S. H. Beasley, drilled in 1903 close to the west ank of Navidad River, about 1 mile north of the crossing of the ew York, Texas and Mexican Railway, has the following record:

Record of Beasley well in central Jackson County.

	Feet.
Sandy soil	0 – ½
Red clay	½– 16
Red sand	16 – 30
Red clay	30 – 46
Rock	46 – 47
Sand	47 – 55
Rock	55 – 56
Sand and red clay in alternate layers	56 –120
Sand	120 –140
Rock	140 –141
Sand	141 –223
Red clay and sand	223 –249
Rock	249 –258½
Clay and rock	258½–268½
Red clay	268½–270½
Sand	270½–285½
Rock	285½–286
Red clay	286 –287
Sand	287 –289
Rock	289 –290
Sand	290 –311
Rock	311 –335½
White clay	335½–339
Sand	339 –361
Rock	361 –387½
Sand	387½–408½
Rock	408½–411
Sand	411 –414
Rock	414 –424
Sand	424 –465
Rock	465 –469
Sand	469 –479
Rock	479 –481
Sand	481 –498
Rock	498 –510
Sand	510 –521
Rock	521 –525
Sand	525 –545
Red clay	545 –548
Sand	548 –558
Red clay	558 566
Sand	566 –586
Rock	586 –596
Sand	596 –640
Blue clay	640 –650
Sand and clay in alternate layers	650 –665
Rock	665 –669
Sand	669 –675

	Feet.
Rock	675- 676
Sand and clay in alternate layers	676- 695
Rock	695- 698
Sand	698- 771
Blue clay	771- 777
Red sand	777- 799
Red clay	799- 852
Red and blue clay	852- 910
Red clay	910- 950
White clay	950- 995
Blue clay	995–1,000
Sand	1,000–1,007
Red clay	1,007–1,009
Water-bearing sand	1,009–1,022
White clay	1,022–1,038
Sand	1,038–1,060
Clay	1,060–1,107
Soft mud	1,107–1,112
Red clay	1,112–1,140
Rock	1,140–1,144
Clay	1,144–1,155
Rock	1,155–1,156
Red clay	1,156–1,200
Soft mud	1,200–1,238
Rock	1,238–1,245
Soft mud	1,245–1,270
Clay	1,270–1,330
Sand, fine water bearer	1,330–1,370

An artesian well owned by Russell Ward, 25 miles from Edna, in the southeast corner of Jackson County, has the following record:

Record of Ward artesian well in southeastern Jackson County.

	Feet.
Surface soil	0- 10
Red clay	10- 20
"Oyster shells"	20- 25
Red clay	25–110
Fine sand, water bearing	110–130
Blue clay	130–155
Thin layer of rock	
Blue clay	155–225
Soft black mud	225–230
"Water sand" and gravel	230–260
Red and white clay	260–290
Layer of thin rock	
Red and white clay	290–330
Sand and gravel, artesian water bearing	330–365

MATAGORDA COUNTY.

ells.—In Matagorda County shallow wells are from 15 to

vells.—Artesian water has been secured at many places, the southern part of the county. Data respecting these ren in the following table:

Artesian wells in Matagorda County.

ner.	Depth.	Diameter.	Flow. Per minute.	Flow. Above surface.	Location.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
.....	356	4	50	8	Bay City, 25 miles southwest.
.....	[a] 380	4	15	4	Bay City, 22 miles southwest.
.....	280	4	10	2	Do.
.....	280	4	10	2	Do.
.....	350	4	50	8	Do.
.....	336	4	15	3	Blessing.
.....	350	4	60	16	Blessing, 3 miles south.
.....	465	4	60	15	Palacios, 4 miles northeast.
.....	485	4	50	10	Palacios, 10 miles south.
o.....	[b] 870	4	20	10	Matagorda, 5 miles northeast.
.....	326	6	30	.5	Midfield.
.....	530	4	75	8	Blessing, 1½ miles west.
.....	125	3	5	2	Markham, 1 mile south.
.....	460	6	100	20	Palacios, 1 mile northwest.
.....	350	4	75	20	Palacios, 5 miles northwest
.....	326	4	25	2	Midfield, 4 miles southwest.
rd.....	440	2	10	4	Wadsworth, 1.5 miles southeast.
.....	[c] 81	4	7	2	Hawkinsville, 6 miles southeast.
d.....	460	6	150	4	Bay City.
Railroad.....	320	6	40	4	Palacios.
.....	444	2	15	1.2	Bay City.
.....	572	4	60	4	Palacios.
.....	620	4	75	6	Do.
.....	1,500	.....	0	.....	Bay City, 9 miles north.
.....	800	.....	0	.....	Palacios.
.....	1,100	.....	0	.....	Ashby.

at 280 feet; bored 100 feet farther and good water obtained.
flows warm sulphur water, which is slightly saline.
nt has about 12 deep wells on his ranch. They average about 80 feet in depth and thin 2 feet of the surface.

WHARTON COUNTY.

ells.—In Wharton County west of Colorado River water ined from wells varying in depth from 15 to 30 feet. In of El Campo many rice farms are supplied with water v wells. Here the water-bearing sand lies about 15 feet rface. A pit 4 to 6 feet in diameter is dug to the water- l and in the bottom of this excavation three or four wells These wells are all cased, and to the top of the casing umps, operated by engines on the surface, are attached. a large supply of water is brought to the surface and used in the irrigation of rice. The most successful shallow- on plants in Texas are in the vicinity of El Campo.

vells.—On account of the shallow depth at which ground secured, few attempts have been made to obtain artesian only artesian well in the county of which a record has known as the Borden well and was drilled in 1892. W

is located near Pierce and has a depth of 1,509 feet. A complete record of the beds penetrated is given below:

Record of A. P. Borden well, Pierce station, Wharton County.

	Feet.
Clay and sand	0– 30
Red sand	30– 35
Quicksand	35– 43
Blue clay	43– 53
Indurated sand	53– 70
Yellow clay and sand	70– 100
Coarse sand	100– 106
Red clay	106– 127
Clay and sand	127– 191
Coarse sand	191– 214
Fine sand	214– 250
Red clay	250– 254
Fine sand	254– 270
Yellow clay	270– 280
Sand and clay	280– 300
Fine white sand	300– 373
Indurated sand, very hard	373– 383
Yellow sand	383– 385
Indurated sand, very hard	385– 410
Yellow sand mixed with thin layers of clay	410– 460
Sand, clay, and gravel	460– 476
Indurated sand, very hard	476– 485
Indurated sand, soft and hard layers alternating	485– 529
Indurated sand, very hard	529– 549
Red and white clay	549– 582
Fine white sand	582– 590
Indurated sand with soft layers	590– 612
Hard clay	612– 650
Very hard sandstone	650– 687
Limestone, very hard	687– 693
Very coarse sand	693– 696
Limestone, very hard	696– 700
White clay	700– 730
Very hard white clay	730– 745
Soft mottled clay	745– 786
Red mottled clay	786– 818
Red sand	818– 838
Quicksand	838– 850
Red clay	850– 890
Gray sand	890– 920
Very hard white clay	920– 938
Gray sand	938– 970
Indurated sand	970– 976
Fine gray sand	976– 996
Hard clay	996–1,000
Hard gray sand	1,000–1,010
White clay	1,010–1,015
White sand	1,015–1,039
White clay	1,039–1,050
Very hard white clay	1,050–1,053

	Feet.
Rock	1,053–1,065
Very hard white clay	1,065–1,076
Sandstone and hard blue clay	1,076–1,128
Water-bearing sand, gray	1,128–1,150
White clay	1,150–1,205
Red clay	1,205–1,359
Fine red sand	1,359–1,366
Red clay	1,366–1,450
White clay	1,450–1,470
White clay with sand	1,470–1,509

In the southern part of Wharton County, near the Matagorda County line, there are two small artesian wells owned by the Texas Land and Cattle Company. These are 2-inch wells, 315 and 513 feet deep, respectively, the former having a flow of 1 gallon and the latter 8 gallons a minute.

BRAZORIA COUNTY.

Shallow wells.—Water is obtained from shallow wells throughout Brazoria County at depths which vary from 15 to 30 feet.

Artesian wells.—Flowing wells are widely distributed throughout the county, on both the east and west sides of Brazos River. They vary considerably in depth, some being over 1,000 feet, and in the amount of flow they range from a few gallons to over 700 gallons a minute. The water is generally of good quality, but from a few wells saline flows have been reported.

Artesian wells in Brazoria County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
... D. Dorchester	1,060	720	8	Velasco.
Quintana	640	60	4	Quintana.
... D. Dorchester	1,000	180	4	Surfside.
Oil-mill site	600	90	4	Velasco.
...uy M. Bryan	1,020	200	4½	Velasco, 6 miles west.
B. H. Hudgins	450	Slight.	2	Velasco, 6 miles east.
Do		....do....	2	Velasco, 3 miles east.
J. S. Hogg	250	100	10	Columbia, 3 miles northwest.
Do	500	100	10	Do.
Do	700	Slight.	10	Do.
State farm	504		10	West of Brazos.
Do	365			Do.
Do	950			Do.
Do	800			Do.
Do	1,030			Do.
Do	1,040			Do.
Do	1,050			Do.
County	1,100		4	Brazoria.
J. P. Bryan	600	90	8	Bryan Heights.
Oil well	1,000			Alvin.
Do	1,000			Do.
H. L. Skeets	911	Slight.	6	Alvin, 3 miles southeast.
R. Willis	785	....do....	3½	Do.
H. Masterson	603	Strong.	6	Alvin, 3 miles south.
E. B. Thomas	772		12	Alvin, 2½ miles southeast.
W. H. Bush	704			Alvin.
E. M. Miller	1,200			Manvell, 2 miles south.
T. J. Moore	650	Strong.		Alvin, 8 miles northwest.
...nta Fe R. R.	700			Alvin.
...illis heirs	760			Sandy Point, 2 miles northwest.
... Dangherty	300			Alvin, 6 miles north.
Do	300			Alvin, 10 miles north.
...ey	600	Strong.		Damon mound.

Record of Arnold well No. 3, Columbia, Brazoria County.

	Feet.
Surface soil, clay, and sand	0 – 85
Rock	85 – 85
Sand	85½– 88
Rock	88 – 89
Oil sand	89½–118
Clay	118 –150
Rock	150 –158
Blue clay	158 –192
Soft rock	192 –196
Sand	196 –210
Soft rock	210 –212
Blue clay	212 –218
Soft rock	218 –219
Blue clay	219 –260
Soft lime rock	260 –261
Blue clay, very tough	261 –275
Rock (hard layer at 294 feet contains some gas)	275 –299
Hard rock	299 –315
Crystallized sand	315 –328
Blue clay	328 –333
Rock	333 –338
Sand	338 –343
Blue clay	343 –346
Compact sand	346 –354
Clay	354 –368
Rock	368 –370
Clay	370 –395
Soft rock	395 –397
Blue clay	397 –405
Rock	405 –406
Blue clay	406 –428
Crystallized sand	428 –462
Blue clay, very hard and oil saturated	462 –484
Soft rock	484 –486
Blue clay	486 –510
Sand, very compact	510 –532
Rock, full of pyrites and shell	532 –534
Sand, very compact	534 –574
Hard rock, conglomerate, pyrites, and lime; rock sulphur and shell	574 –582
Hard blue clay	582 –620
Rock, pyrites, sulphur, lime, volcanic crystals, and oil saturations	620 –628
Blue clay	628 –632
Rock with sand	632 –651
Sand	651 –657
Rock	657 –675
Hard rock	675 –676
Sand	676 –678
Very hard rock	678 –680
Sand, color of oil	680 –681
Rock, very hard	681 –682
Sand	682 –691

	Feet.
Blue clay	691 – 719
Sand	719 – 723
Blue clay	723 – 729
Oil sand	729 – 734
Blue clay	734 – 800
Sand	800 – 835
Shell with some little showing of oil	835 – 857
Blue clay, very thin strata full of shell	857 – 858
Sand	858 – 870
Blue clay	870 – 906
Crystallized sand	906 – 926
Rock	926 – 936
Blue clay	936 – 943
Sand	943 – 970
Soft sandstone	970 – 971
Hard sandstone	971 – 973
Clay	973 – 989
Sand	989 –1,002
Hard rock	1,002 –1,004
Sand, fairly firm, contains fossil wood	1,004 –1,012
Hard clay	1,012 –1,050
Sand with a little gas	1,050 –1,110
Blue clay	1,110 –1,115
Sand	1,115 –1,136
Soft rock, or compact sand	1,136 –1,214
Clay, blue with a greenish cast.	

Record of well on lot 234, Hoskins Mound (midway between Velasco and Alvin), Brazoria County.

	Feet.
Black surface clay	0 – 4
Pale blue clay	4 – 12
Red clay	12 – 25
Yellow loamy sand, rather fine	25 – 45
Blue gumbo	45 – 85
Blue quicksand	85 –130
Blue clay filled with small white shells	130 –152
Blue quicksand	152 –172
Blue gumbo, very tough	172 –233
Blue sand, fine grained, with black specks; first indication of oil.	233 –239
Sand with some clay	239 –378
Blue sand, coarse, with black specks; some oil near bottom	378 –423
Blue clay with some small shells	423 –465
Coarse blue sand with black specks	465 –500
Blue sand with some brown layers, contains iron pyrite and some small shells	500 –530
Soft blue clay with small shells	530 –535
Blue clay with larger shells	535 –555
Blue clay with few shells	555 –580
Blue gumbo, very tough; shells	580 –595
Tough blue clay with few shells	595 –628
Blue sand with gravel and some shells	628 –632½
Blue sand with coarse black particles	632½–642½
Blue clay with large shells	642½–654
Blue clay with shell fragments	654 –674

	Feet.
Blue sand, gravel with black particles; considerable gas	674 –684
Blue sand with many black particles; good show of oil from 688 to 692 feet	684 –692
Bluish sand, coarse; shows oil saturation	692 –711
Tough blue clay containing shells	711 –720
Tough blue gumbo containing bowlders	720 –722
Blue clay and sand; show of oil	722 –728
Blue clay with thin layers of sandstone	728 –735
Tough blue gumbo	735 –755
Blue gumbo with thin layers of sandstone and limestone	755 –778
Blue sand with iron pyrites; some show of oil at 778 feet	778 –783
Tough blue gumbo with thin layers of sandstone and limestone; considerable iron pyrites	783 –786
Blue gumbo with shells	786 –793
Sand with iron pyrites; "oil show"	793 –794
Tough blue gumbo	794 –799
Very hard blue clay with rock 2 to 6 feet thick, mostly limestone.	799 –825

FORT BEND COUNTY.

Shallow wells.—Water in sufficient quantity for ordinary domest purposes is obtained throughout Fort Bend County at depths 15 to 40 feet.

Deep wells.—A few deep pump wells have been sunk. Two on t Cunningham farm near Sugar Land are 1,000 feet deep. The to of Richmond derives its water supply from a pump well 400 fe deep. The following is a list of some of the deeper wells in tl region.

Deep wells in Fort Bend County.

Owner.	Depth.	Capacity.	Location.
	Feet.	*Gallons.*	
T W. House	925	60	Arcola, 2 miles southwes
Do	1,000	60	
City waterworks	400	.....	Richmond.
Cunningham farm	1,000	.....	Sugar Land.
Do	1,000	.....	Do.

HARRIS COUNTY.

Shallow wells.—Good shallow wells have been bored in Har County, at Clodine, Erin, Katy, and Deepwater, and it is believ that wells of this character may be obtained throughout the coun In the vicinity of Clodine, on the rice farms of the Meadow Bro Company, the wells are generally 150 feet deep and 10 inches diameter, the water rising within 15 to 20 feet of the surface. We on the J. H. O'Donnell farm, at Erin, are less than 100 feet de and penetrate 46 feet of water-bearing sand. At Katy the two we of J. E. Cabaniss are 93 and 94 feet deep.

Artesian wells.—There are about 140 artesian wells in Har County, 80 of these being at Houston, where the artesian wa resources have been better developed than in any other part of t

e city water supply of Houston is derived from 60 artesian
ı have been drilled in an area of 14 acres lying on either
falo Bayou. The general distribution of these and other
lls in Harris County is shown in Pl. II (p. 2), and the fol-
es contain all available information concerning them:

Artesian wells in Harris County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
.....	570	Flows.	.....	Webster, 1 mile south.
.....	520	Flows.	.....	Webster.
.....	670	Flows.	.....	Webster, ½ mile east.
.....	475	Flows.	.....	Webster, 3 miles northeast.
.....	615	Flows.	.....	Webster, 1 mile north.
.....	470	Flows.	.....	Do.
.....	500	Flows.	.....	Webster, 3 miles east.
.....	450	Flows.	.....	Webster, ½ mile northeast.
.....	650	Flows.	.....	Genoa.
.....	600	Flows.	.....	Do.
.....	90	Flows.	.....	Genoa, 2 miles north.
.....	250	Flows.	.....	Genoa, 2 miles south.
.....	250	Flows.	.....	Genoa, 4 miles south.
.....	700	Flows.	3	Genoa.
.....	300	Flows.	.....	Genoa, 1 mile south.
.....	660	Flows.	.....	Seabrook, 3 miles northeast.
.....	640	Flows.	.....	Seabrook, 1¼ miles northeast.
.....	670	70	3	Seabrook, ½ mile northeast
.....	660	Flows.	.....	Seabrook.
wells).....	440–500	Flows.	3	La Porte.
.....	440	350	6	Do.
.....	380	170	4	La Porte, Spillway Island.
iton and Northern R. R....	450	Flows.	.....	Strange.
.....	450	Flows.	.....	Do.
.....	.....	Flows.	.....	Morgan Point.
.....	440	Flows.	.....	Do.
.....	217	Flows.	.....	Wooster, 1 mile west.
.....	330	Flows.	.....	Deepwater.
.....	340	Flows.	.....	Deepwater, 1 mile north.
.....	340	Flows.	.....	Deepwater, 1½ miles north.
.....	340	Flows.	.....	Deepwater, 2 miles north.
.....	330	Flows.	.....	Deepwater, 1 mile southeast.
.....	230	Flows.	.....	Deepwater, 1 mile northeast.
.....	300	Flows.	.....	Deepwater, 2 miles northwest.
.....	300	Flows.	.....	Do.
.....	344	Flows.	.....	Deerspark.
.....	324	Flows.	.....	Do.
R. R.....	330	Flows.	.....	Do.
.....	290	Flows.	.....	Pasadena.
.....	310	Flows.	.....	Do.
.....	180	Flows.	.....	Do.
.....	210	Flows.	.....	Do.
.....	659	100	.....	Harrisburg, 1 mile east.
.....	500	Flows.	.....	Alameda, 1.5 miles north.
.....	450	Flows.	.....	Alameda, 3.5 miles east.
.....	65	Flows.	.....	Aldine, ½ mile northeast.
.....	400	Flows.	.....	Aldine, 4 miles southeast.
.....	240	Flows.	.....	Aldine, 5 miles northwest.
.....	280	Flows.	.....	Aldine, 4 miles west.
.....	88	Flows.	.....	Barker, 2 miles south
.....	180	Flows.	.....	Addicks, 3 miles southwest.
.....	500	Flows.	.....	Humble.
ry Co.....	150	35	.....	Houston.
.....	300	209	.....	Do.
.....	200	104	.....	Do.
.....	500	249	.....	Do.
.....	500	250	.....	Do.
.....	500	490	.....	Do.
.....	800	Flows.	.....	Do.
ry Co.....	180	40	.....	Do.
.....	242	125	.....	Do.
.....	339	75	.....	Do.
.....	800	95	.....	Do.
.....	570	45	.....	Do.
.....	830	175	.....	Do.

Artesian wells of waterworks at Houston, Harris County.

No.	Depth.	Diameter.	No.	Depth.	Diameter.	No.	Depth.	D
	Feet.	*Inches.*		*Feet.*	*Inches.*		*Feet.*	
1	140	15	20	1834	4	38	325	
2	140	6	21	314	8	39	684	
3	80	6	22	703	8	40	211	
4	140	15	23	692	8	41	319	
5	140	15	24	192	6	42	720	
6	140	15	25	204	6	43	806	
7	140	15	26	802	8	44	496	
8	154	6	27	1,170	8	45	800	
9	312	8	28	814	8	46	1,185	
10	328	6	29	502	10	47	2,018	
11	130	6	30	1,165	12	48	1,214	
12	328	4	31	317	8	49	1,305	
13	292	8	32	319	12	50	1,280	
14	292	8	33	823	10	51	936	
15	460	8	34	1,185	9	52	936	
16	460	6	35	1,171	12	53	501	
17	504	8	36	292	8	54	828	
18	115	6	36	314	12	55	635	
19	493	8	37	1,173	12			

Record of well No. 28, Houston, Harris County.

	Feet.
Surface soil	0– 3(
Clay	30– 4(
Sand and rock	44– 7(
Clay	74– 8(
Sand and gravel	89– 9(
White clay	93–13(
Sand	137–21(
Clay and gravel	210–29(
White sand and gravel, water bearing; hard to finish	290–31(
Clay and gravel	316–35(
Red sand	356–39(
Clay and gravel	393–45(
White clay and gravel	456–49(
Sand, clay, and gravel	496–514
Sand	514–526
Gravel	526–532
Clay	532–570
Limestone	570–571
Sand and gravel	571–585
Clay	585–600
Hard rock	600–602
Clay	602–608
Sand	608–618
Clay	618–658
Clay and gravel	658–668
Sand	668–678
Clay and sand	678–687
Sand	687–705
Clay and gravel	705–745
Sand	745–756
White clay	756–772
Water-bearing sand	772–814

Record of deep well at Houston, Harris County.

	Feet.
Clay and sand	0 – 154
Sand, water bearing	154 – 161
Clay	161 – 163
Sand	163 – 210
Clay	210 – 280
Sand	280 – 312
Clay	312 – 345
Rock	345 – 345½
Sand	345½ – 350
Clay	350 – 415
Sand	415 – 420
Clay	420 – 465
Sand	465 – 502
Clay	502 – 540
Sand	540 – 570
Clay	570 – 605
Sand and gravel	605 – 643
Clay	643 – 670
Sand and gravel	670 – 702
Clay	702 – 745
Sand	745 – 769
Clay	769 – 779
Sand	779 – 805
Clay	805 – 810
Sand	810 – 835
Clay	835 – 895
Sand	895 – 940
Clay	940 – 1,134
Rock	1,134 – 1,137
Sand	1,137 – 1,179
Clay	1,179 – 1,236
Sand	1,236 – 1,314
Rock	1,314 – 1,315
Clay	1,315 – 1,334
Sand	1,334 – 1,368
Clay	1,368 – 1,430
Sand and gravel	1,430 – 1,470
Clay and rock	1,470 – 1,600
Rock with gas	1,600 – 1,605
Clay	1,605 – 1,895
Sand	1,895 – 1,907
Clay	1,907 – 2,025

GALVESTON COUNTY.

Shallow wells.—In Galveston County the average depth of shallow wells is 25 feet.

Artesian wells.—The log of the deep well at Galveston, bored about 1892, clearly indicates that artesian water could be found in the coast region at much shallower depths than that reached by this boring. The record down to the water-bearing sand is given below. There are at present about 90 artesian wells in Galveston County. Their

approximate location is shown in Pl. II. The most important grou of these wells is located 18 miles from Galveston, at Alta Loma, whe 30 wells have been drilled on both sides of the Santa Fe Railwa track. The original contract for these wells specified that 33 wel should be bored and a supply of 5,000,000 gallons every twenty-fou hours guaranteed. When 30 wells had been sunk, the yield wa 9,000,000 gallons every twenty-four hours, 4,000,000 gallons mo than the contract amount. The wells are located in a line that trend nearly north and south, and there are about an equal number on eac side of the railroad track. They are provided with pipes that connec with mains to a standpipe on the north side of the track. The wel are about 868 feet deep, and all receive their water from a bed o water-bearing sand 128 feet thick, which rests upon a layer of har clay. This water horizon was encountered in all wells at a depth o 740 to 750 feet, but some were not bored through the water-bearin sand. The following table shows the depths of wells on the south sid of the railroad:

Partial list of wells at Alta Loma, Galveston County.

No.	Depth.	Diameter.	No.	Depth.	Diameter.	No.	Depth.	Diameter
	Feet.	*Inches.*		*Feet.*	*Inches.*		*Feet.*	*Inches*
2	792	7	12	788	5	22	726	
4	808	7	14	800	5	24	733	
6	793	7	16	838	5	26	745	
8	809	5	18	790	5			
10	792	5	20	775	5			

Record of well at Alta Loma, Galveston County.[a]

	Feet.
Surface soil	0– 4
Clay	4– 12
Quicksand	12– 18
Very red clay	18– 25
Red quicksand	25– 35
Clay	35– 37
Quicksand	37– 40
Red and white clay	40–100
Sand, water bearing; no flow	100–123
White clay	123–150
Red clay	150–173
Very hard red clay	173–190
Hard and soft clay	190–208
Soft red clay	208–218
Hard clay	218–230
Quicksand	230–385
Hard and soft white clay	385–435
Soft white clay	435–478
White sand and clay	478–488
Very hard shell rock	488–489
White water-bearing sand; first flow	489–494

[a] Information furnished by E. H. Stobard.

	Feet.
Hard white clay	494–500
Soft white clay	500–514
Hard and soft white clay	514–560
Hard white clay	560–590
Quicksand	590–611
Hard clay	611–620
Soft clay	620–631
Hard and soft clay	631–703
Sand and clay	703–735
Hard white clay	735–740
Sand, water bearing	740–868
Hard red clay	868–

Artesian wells in Galveston County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
D. Collogue	640	200	.....	Dickinson.
W. H. Crawford	675	(a)	8	Dickinson, 1 mile east.
J. D. Ward	700	.....	6	Dickinson, 2½ miles east.
C. C. Pellit	620	4	6	Dickinson, 2 miles east.
F. Fonts	600	10	6	Dickinson, 1 mile south.
John Williams	750	(b)	6	Dickinson, 2 miles north.
Sam Saloets	550	2	.....	Dickinson, ½ mile northeast.
Charles Engelke	700	(a)	.....	Dickinson, 1½ miles east.
Mick Weeks	675	100	.....	Dickinson, ½ mile southwest.
Joe Lohit	640	100	.....	Dickinson.
Do	640	100	.....	Do.
Do	640	100	.....	Do.
Charles Nolan	600	.....	.....	Dickinson, 1 mile south.
Do	650	.....	.....	Dickinson, 2½ miles south.
C. H. Collier	.....	.....	.....	Dickinson, ½ mile south.
Nicolini	640	.....	.....	
R. A. Walker	750	40	.....	League City.
A. W. Wilkerson	550	40	.....	Do.
Do	530	40	.....	Do.
J. C. League	526	40	.....	Do.
C. R. Reifel	562	25	.....	Do.
Do	410	25	.....	Do.
Mrs. L. Cours	420	20	.....	Do.
Mrs. R. T. Wheeler	690	57	2	Hitchcock, ½ mile east.
Do	763	80	3	Hitchcock, ½ mile north.
A. H. Tacquard	406	80	4½	Hitchcock, 8 miles west.
Do	300	25	3	Hitchcock, 7 miles west.
Do	306	30	2	Hitchcock, 6 miles west.
Do	60	10	2	Hitchcock, 7 miles west.
Do	88	12	2	Hitchcock, 8 miles west.
Do	88	12	2	Do.
Jacques Tacquard	763	25	3	Do.
Do	180	15	2	Do.
A. H. Tacquard (home)	710	100	3	Hitchcock, 1½ miles west.
A. H. Tacquard (pasture)	720	80	3	Hitchcock, 2 miles southwest.
Jules Perthius	230	25	3	Hitchcock, 2 miles east.
Do	495	65	3	Do.
W. F. Reitmeyer	433	10	2	Hitchcock, 1½ miles west.
Do	420	80	3	Do.
J. Jinsen	500	48	3	Hitchcock, 1 mile east.
J. A. Minot	763	64	2	Hitchcock, ½ mile south.
David Tahey	576	68	3	Hitchcock, 1½ miles east.
B. F. Fast	702	120	3	Hitchcock, 2½ miles west.
Gulf, Colorado and Santa Fe R. R	720	78	3	Hitchcock, 100 yards east.
J. H. Kemper	600	60	3	Hitchcock, 1 mile east.
Alta Loma Co	914	40	3	Hitchcock, 4 miles northwest.
Galveston, Houston and Henderson R. R	867	700	10	Hitchcock, 4 miles east, at La Marque.
W. McClintoc	630	50	4	Bay View.
Galveston, Houston and Northern R. R	600	55	3	Edgewater.
J. R. Myers	725	70	4½	Texas City.
Inman Compress Co	912	70	4½	Do.
South Galveston Land Co	640	40	3	Middle of island.
Do	644	40	3	Do.
Galveston Brewing Co	872	Flows.	8	

a Water rises 10 feet above surface. b Water rises 8 feet above surface.

Record of deep well at Galveston.

	Feet.
Pleistocene:	
Gray to buff sand	0–46
Reddish-brown clay containing lenses of sandstone, quartz pebbles, nodules of dark-gray clay, and shell fragments	46–63
Mottled red and blue clay containing shell fragments and in lower part lignitic material	63–100
Gray sandy clay	100–110
Fine gray sand with fragments of lignite	110–167
Buff-colored sandy clay	167–279
Fine gray sand with fragments of lignite	279–305
Grayish-brown clay with fragments of lignite	305–315
Fine sand, gray to buff, with fragments of lignite throughout bed and lower 35 feet slightly micaceous	315–440
Grayish-brown clay with fragments of lignite, shells, corals, and claw of crustacean	440–458
Age doubtful:	
Gray sandy clay, slightly micaceous	458–468
Brownish-gray sandy clay	468–497
Fine light-gray clayey sand, micaceous	497–575
Brownish-gray sandy clay	575–592
Gray sand, micaceous	592–612
Brownish sandy clay with shell fragments	612–647
Light-gray sandy clay	647–674
Reddish-brown sandy clay with shell fragments	674–706
Buff-colored sand, slightly micaceous	706–720
Brownish-gray clayey sand	720–737
Light-gray clayey sand, the lower 11 feet containing a few shell fragments and large pieces of lignite	737–827
Coarse silver-gray sand, composed of angular fragments of translucent and smoky quartz not much water-worn (the water-bearing sand from which most of the city's water supply was derived previous to the utilization of the Alta Loma wells)	827–882

This well was drilled to a depth of 3,070 feet, but practically no water-bearing sand of importance was found below 882 feet. The complete record is published in the Twenty-first Annual Report of the U. S. Geological Survey, part 7, pages 402–405.

CHAMBERS COUNTY.

Shallow wells.—Beneath the surface soil in Chambers County there is a bed of sand which extends to a depth of 30 feet or more. In its lower part this sand contains an abundance of excellent water which is the source of supply for all shallow wells in the region.

Artesian wells.—There are 17 artesian wells in Chambers County and their approximate location is indicated in Pl. II. At many places artesian water has been obtained, but it is salty in many cases, especially in wells near the bay.

Artesian wells in Chambers County.

Owner.	Depth.	Flow per minute.	Location.
	Feet.	*Gallons.*	
E. W. Barber	800	Flows.	Mount Belvieu.
Mat Fisher	550	Flows.	Mount Belvieu, 10 miles south.
J. C. Fisher (estimate) [a]	500	Flows.	Cedar Bayou.
Dr. N. Schilling	700	Flows.	Do.
Do	700	Flows.	Do.
Barney Donelly	375	Flows.	Mount Belvieu, 3 miles south.
Amos Lawrence	500	Flows.	Mount Belvieu, 5 miles south.
C. R. Cummings Co	400	Flows.	Anahuac, 4 miles north.
Do	400	Flows.	Do.
John Cook	380	Flows.	Wallisville.
W. D. Wilcox	850	35	Anahuac, Turtle Bayou.
J. T. White [a]	1,720	Flows.	
D. L. Broussard	850	100	Double Bayou.
Sol. Brown	800	100	Do.
Hugh Jackson		100	Double Bayou, 15 miles southeast.
James Jackson	1,000	100	Double Bayou, 15 miles northeast.
—— Davidson	600	100	Near Stowell.

[a] Water salty.

JEFFERSON COUNTY.

Shallow wells.—The wells of Jefferson County are very shallow, ranging from 6 to 15 feet in depth. Many of those 6 feet deep furnish an abundance of water.

Artesian wells.—Information has been obtained of about 31 artesian wells in this county, but such wells are not generally successful. Many of them have feeble flows, making it necessary to employ pumps to increase the discharge, while in other cases, where the flows are sufficiently large, the water is more or less salty. A large number of wells have been drilled for oil in the vicinity of Spindletop, south of Beaumont. The following is a list of artesian wells in Jefferson County, with other data concerning them. A record of the Stribling well is also given.

Artesian wells in Jefferson County.

Owner.	Depth.	Flow per minute.	Location.
	Feet.	*Gallons.*	
W. C. Tyrrell	180	Slight.	
H. De Mondrot	430	25	
Port Arthur	450	40	
McKinney	620	Slight.	
Jefferson Rice Co	530	Slight.	
Jes Garland	450	65	
J. W. Denny	260	Slight.	
H. C. Wheeler (5 wells)	230	Slight.	Hampshire, 1½ miles south.
D. N. Coffol	306	25	
A. J. Snouffer	180	25	Hampshire, 1½ miles north.
Do	200	25	
C. T. Heisig	230	Slight.	
Do	180	No flow.	
Do	150	No flow.	
Doctor Price	190	Slight.	
H. Aldridge	135	Slight.	
Geo. J. McManis	180	20	Stowell, 2 miles east.
H. Aldridge	135	Slight.	
Geo. J. McManis	178	20	
Do	267	20	
Do	180	20	
Do	653	45	
R. P. Carroll	280	25	
Court-house [a]	745	30	
Natatorium [b]	796	150	Port Arthur.
Hotel [b]	1,065	100	Sabine Pass.
J. F. Keith [c]	534	10	Beaumont.

[a] Diameter, 3 inches. [b] Diameter, 4½ inches. [c] Diameter, 6 inches.

Record of Stribling well, Sabine Pass, Jefferson County.

	Feet.
Red clay	0– 16
Red sand	16– 20
Red clay	20– 60
White sand	60– 80
Red clay	80– 140
Coarse sand	140– 170
Blue clay	170– 185
White sand	185– 220
Soft blue clay	220– 236
Fine white sand	236– 250
Hard blue clay	250– 260
White sand	260– 270
Blue clay	270– 355
White sand	355– 426
Blue clay	426– 442
Interbedded sand and clay	442– 500
White sand	500– 600
White sand with gravel at bottom	600– 636
Blue clay with streaks of sand	636– 740
Sand	740– 764
Sand and coarse gravel, all colors	764– 795
Hard sandstone	795– 796
Blue shale	796– 854
Hard sandstone	854– 855½
Blue shale	855½– 892
Sandstone	892– 893
Fine white sand	893– 960
Soft blue clay	960–1,000
Fine white sand	1,000–1,260
Blue and white shale	1,260–1,270
Fine white sand	1,270–1,360
White and blue clays	1,360–1,450
White sand	1,450–1,490
Solid white and blue shale	1,490–1,500

ORANGE COUNTY.

Shallow wells.—The deepest of the shallow wells of Orange Coun are about 22 feet in depth, and a large supply of water is usua obtained.

Artesian wells.—There are a few artesian wells at Orange, varyi in depth from 400 to 800 feet. Their flows are moderate, but f exceeding 50 gallons a minute. A partial list of these wells is giv below:

Artesian wells in Orange County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
.....	600	15	.....	Orange.
.....	467	21	4	Do.
.....	467	22	3	Do.
.....	500	10	.....	Do.
it.....	650	.....	.....	Do.
.....	480	52	6	Do.
.....	800	Slight.	.....	Orange, 9 miles northwest.
.....	740	60	6	8 miles from Beaumont.
rleans Railroad.....	396	.....	8¾	Echo.
.....	435	35	6	Echo, 1 mile from Sabine River.

ZAPATA COUNTY.

ells.—Shallow wells are difficult to obtain in the northern ıta County. Near the Rio Grande and along the eastern :ounty water can be obtained at moderate depths, but in nds the depths of the wells vary from 100 to 250 feet.

vells.—No information has been received concerning the ditions of this county.

DUVAL COUNTY.

ells.—Wells in Duval County can be obtained at depths n 50 to 300 feet.

vells.—No artesian wells have been reported from Duval rtesian water is found, however, in the southern part of nty, in the northeastern part of Starr County and at ın the Texas and Mexican Railroad, in the eastern part of ty. The northern part of Duval County lies between ı districts; that at Kingsville, Nueces County, and that Lasalle County. Artesian water is also obtained in the ıt 30 miles north of the northern boundary of Duval

LIVE OAK COUNTY.

ells.—Shallow-well water is obtained in the southern and :s of Live Oak County, at depths of 100 to 120 feet; in part at about 200 feet, and in the northern part at 300

Artesian wells.—Artesian water is found in the northern part of this county. The following table gives a list of the artesian wells:

Artesian wells in Live Oak County.

Owner.	Depth.	Flow.	Location.
	Feet.		
Geo. W. West	155	Slight	Oakville, 13 miles northwest.
Do	226	Slight	
Thos. R. T. North	375	Small	Oakville.
C. T. Tom	450	(a)	Oakville, 18 miles northwest.
Mrs. B. McGloin	150	Flows	Near Mikeska.

a Water at 6 feet below surface.

BEE COUNTY.

Shallow wells.—In the northern and southern parts of Bee County wells have an average depth of about 40 feet, in the eastern part about 70 feet, and in the western part about 100 feet.

Artesian wells.—No information has been obtained regarding the artesian condition of this county. There are at present no artesian wells in Bee County.

GOLIAD COUNTY.

Shallow wells.—In Goliad County water is found in shallow wells at depths varying from 50 to 125 feet.

Artesian wells.—There are no artesian wells in this county. On the ranch of T. M. O'Connor, 6 miles south and 20 miles east of Goliad, on the head of Little Carco Creek, a boring was made to a depth of 1,446 feet, but no artesian water was obtained.

KARNES COUNTY.

Shallow wells.—In Karnes County a good supply of water is obtained from shallow wells having the following average depths: In the northern part, 60 feet; in the eastern part, 80 feet; in the southern part, 90 feet; in the western part, 120 feet.

Artesian wells.—There are at present no artesian wells in Karnes County. At Karnes City a test well was sunk to a depth of 1,800 feet, but no artesian water was found. It is possible that more extensive prospecting in other parts of the county may result in the discovery of flows at shallower depths.

DEWITT COUNTY.

Shallow wells.—Throughout Dewitt County shallow wells are obtained at an average depth of about 55 feet. The principal water supply appears to lie in sheets, so that the depths of the wells vary according to the elevation of the surface.

Artesian wells.—The only artesian water thus far obtained in Dewitt County is at Yorktown and Yoakum. At Yorktown there were formerly 8 or 10 small artesian wells, flowing 5 gallons a minute and varying in depth from 50 to 60 feet, but at present only two of these flow, the others having been allowed to cave in or to become choked with sand at the bottom. The two wells which continue to flow are in the bed of Yorktown Creek. Many of the wells in the town show a strong artesian tendency, the water rising within 10 feet of the surface. At Yoakum several deep wells have been drilled and in nearly every case the water rises within a few feet of the surface, but no wells are recorded in which flows were obtained. In the deepest well, 1,300 feet deep, the water is soft, relatively pure, and admirably suited for general domestic uses. It is noncorrosive and well adapted to boiler purposes. According to some analyses it contains only 42 grains of solid matter per gallon and no organic matter.

Record of H. G. Brown's artesian well, 7½ miles southwest of Cuero, Dewitt County.

	Feet.
Red and yellow clay, with cobblestone	0 – 60
Hard rock, fine grained	60 – 120
Water-bearing sand	120 – 121
Gravel and clay, hardpan	121 – 181
Very hard gritty rock	181 – 202
Sandstone	202 – 365
Yellow clay and hard rock	365 – 490
Sand, water bearing	490 – 690½
Stratified rock	690½ – 710
Red, white, and blue clay	710 – 805
"Talc," with an occasional layer of red and blue clay	805 – 1,050
Pale-blue "talc;" strong indications of water	1,050 – 1,100
Clear glassy rock, soluble in acid; slacks if exposed to the air	1,100 – 1,130

GONZALES COUNTY.

Shallow wells.—The shallow wells of Gonzales County show considerable variation in depth, ranging from 20 to 80 feet.

Artesian wells.—In the western part of Gonzales County the artesian water resources have been extensively developed. There are 125 artesian wells in the vicinity of Leesville, Rancho, and Wrightsboro. They vary considerably in depth, ranging from 100 to 700 feet, and their maximum flow is 100 gallons a minute. The average flow, however, is much less than this, as shown in the following table, which contains a partial list of these wells, with their depth, flow, and approximate location.

Artesian wells in Gonzales County.

Post-office and owner.	Distance and direction from post-office.	Depth.	Fl m
		Feet.	G
Wrightsboro:			
J. G. Barnett	2 miles southwest	640	
R. R. Hinton	1½ miles northwest	420	
W. T. Mahon	2 miles west	363	
Do	2½ miles northwest	400±	
W. B. Houston	3 miles southwest	316	
Do	do	408	
H. G. Barnett	3 miles northwest	347	
J. D. Tankersley	¾ mile northeast	269	
Dewet:			
J. D. Tankersley	1 mile northeast	290±	
W. L. Caraway	100 yards south	313	
Do	½ mile southeast	200±	
J. R. Keadings		311	
John Worthy	¾ mile west	528	
F. M. Caraway	1½ miles northeast	500±	
John Caraway	1½ miles northeast	260±	
M. V. Caraway	1 mile southwest	300±	
Albert Tankersley	¾ mile northeast	268±	
E. O. Perkins	¾ mile south	231	
Leesville:			
Jay Mahan [a]	3 miles southeast	222	
Do	do	527	
W. F. McGlasson [b]	do	176	
C. C. Littlefield	1½ miles south	600±	
Do	2 miles northwest	360±	
Do	3 miles west-northwest	350±	
Do	2 miles west	212	
Do	1½ miles northwest	284	
Do	2 miles west	216	
John Bratton	½ mile southwest	470±	
Do	1 mile south	250±	
Jno. Glazier	½ mile southwest	448	
F. C. Baker	1 mile northeast	500±	
W. M. Carr	1½ miles north	439	
Gus Scofje	2½ miles north	400±	
Otto McNemar	2 miles north	435	
J. A. Williams	2½ miles north	480±	
K. J. Hawkins	2 miles north-northeast	400±	
J. E. Martin	1 mile southwest	290±	
Davenport	4 miles west-northwest	250±	
J. B. Wells	1¾ miles north	185	
Do	3 miles northwest	200±	
Do	3+ miles northwest	180	
Do. [c]	2 miles northwest	200±	
Do. [d]	2½ miles northwest	200±	
Do. [e]	2¾ miles northwest	200	
Do. [f]	1½ miles northwest	200	
Do	2½ miles north	250	
Do. [d]	3¼ miles north	350	
Do	3½ miles north	350	
Do. [e]	3 miles north-northwest	200	
Do	do	350	
S. A. Brown	200 yards north	441	
W. H. Brown	400 yards east	504	
Do	300 yards east	643	
Do	600 yards north	450	
F. M. Caraway	50 yards west	460	
J. G. McGuffin	250 yards southwest	143	
S. A. Hubbard	150 yards southwest	160	
Doctor Littlefield	75 yards south	166	
Do	50 yards west	160	
Do	750 yards south	490	
J. P. Watkins	500 yards southwest	160±	
I. A. Pruett	200 yards east	250±	
Dr. J. M. Fly	100 yards northeast	170±	
Do	135 yards northeast	170±	
A. B. Holmes	400 yards west	488	
Geo. Brown	500 yards north	450±	
Geo. Williams	350 yards west	200±	
J. C. West	300 yards northeast	450	
J. M. Caraway	200 yards northeast	170	
Sol. Gordon	5 miles southwest	420	
W. H. Brown	6 miles southwest	450	
Gus Varner	6 miles west	350	
Rancho:			
H. Wicke	½ mile northeast	180	
Do	1 mile northeast	297	
W. M. Mangum	½ mile east	500	
Do	2 miles north	300	

[a] First water at 135 feet; second at 222.
[b] Four wells with 4-inch pipe casing.
[c] Casing, 3-inch pipe.
[d] First water.
[e] Casing, 6-inch pipe.
[f] Casing, 4-inch pipe.

Artesian wells in Gonzales County—Continued.

Post-office and owner.	Distance and direction from post-office.	Depth.	Flow per minute.
[illegible]cho—Continued.		*Feet.*	*Gallons.*
W. M. Mangum	1 mile east-northeast	185	30
James Pace	3 miles east	360	5
Doctor Green	1¼ miles northeast	420	20
Do	do	175	10
Do	3 miles northeast	400	12
Do	¼ mile northeast	325	15
— T. Davis	250 yards	509	10
— J. New	200 yards east	450	6
W. Littleton	1 mile northwest	140	10
R. Murray	400 yards north	130	4
[illegible]el Murray	1 mile north	180	10
[illegible]s. Murray	500 yards southeast	230	5
W. Magee	100 yards south	475	15
— A. Williams	1½ miles north	300	5
— P. McDonald	1½ miles north-northwest	280	5
T. Nixon	1 mile southwest	400	6
George McPeters	½ mile northwest	117	7
H. Patterson	1 mile east	270	10
[illegible]rs. C. E. Hall	¼ mile northeast	300	1
— C. Hall	600 yards northeast	350	25
Do	2¼ miles northeast	450	10
[illegible]ller & Sayers	100 yards east	385	20
W. H. Magee	4½ miles east-northeast	430	15
F. Weinert	5 miles southwest	406	10
J. D. Houston	3¼ miles south	420	15
J. L. Weber	4 miles southeast	537	3
Geo. Parks	3 miles southeast	531	40
Do	4 miles southeast	505	30
Frank Clark	1½ miles east	400	7
W. B. Clark	1½ miles east	300	5
S. W. Fanning	2½ miles east-northeast	260	15
M. G. Fanning	3 miles east-northeast	225	13
Jeff Patterson	3½ miles east	337	6
Do.[a]		450 700	25 10

[a] This well has two casings, one inside the other. The outer is 450 feet deep and furnishes salt water (25 gallons) and gas. The inner is 700 feet deep and furnishes good water.

The following is the record of a representative artesian well, situated on the Gentry ranch, on Sandy Fork of Peach Creek, 12 miles northeast of Gonzales.

Record of Charles Gentry's artesian well, Gonzales County.

	Feet.
Clay and flint bowlders	0 – 45½
Rock	45½– 46
Blue sand and clay	46 – 68
Blue clay, very little sand	68 –157
Hard sandstone, fine grained (10 inches of water sand at this depth; trace of oil; lignite plentiful)	157 –195
Sand, water and oil bearing	195 –195¾
White quartz	195¾–196½
Sandstone hard, fine grained (trace of oil)	196½–218
Blue clay	218 –220
Sandstone (trace of oil)	220 –222
Black clay, containing decayed wood	222 –228
Sandstone (trace of oil)	228 –263
Blue marl	263 –285
Quartz	285 –286
Blue marl, spongy	286 –304
Shale with soft strata	304 –321
Hard blue sandstone	321 –339

	Feet.
Hard cement rock	339–37
Clay, sand, and shell	378–38
Rock	380–38
Clay, sand, and shell	381–38
Hard rock	383–38
Clay and sand (trace of oil)	384–40
Dark blue clay and sandstone	405–40
Clay and sand	406–41
Clay and shell	410–46
Clay, little shell; thin hard rock at intervals	463–50
Shells and clay	501–57
Clay and shell (water bearing)	579–70
Hard rock	708–70

LAVACA COUNTY.

Shallow wells.—An abundance of water is obtained in La County from wells which vary in depth from 30 to 40 feet.

Artesian wells.—A number of good artesian wells have been obta in Hallettsville and the surrounding country. In the wells at lettsville two flows have been found, one at 300 feet and the oth 560 feet below the surface. The oil-mill well encountered the flow at 320 feet, which furnished a supply of 45 gallons per mir while the second flow at a depth of 560 feet furnished 88 gallo minute. At Shiner a flowing well was obtained at a depth of 90 which yielded 79 gallons a minute. The well was located on ground and the water rose 6 feet above the surface. Several atter to obtain water from this horizon on higher ground, in the vicinit Shiner, have been unsuccessful, one boring being continued to a d of 700 feet without striking a flow. The following is a list of artesian wells in this county:

Artesian wells in Lavaca County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons*	*Inches.*	
City	600	30	4	Hallettsville.
Do	560	89	4	Do.
Do	325	45	4	Do.
Do	980	140	4	Do.
Oil mill	560	30	4	Do.
Ice factory	340	30		
J. Keusler	768		4	Breslau.
C. Pagelest	340	30	4	Hallettsville, 4 miles r
Trautwine & Walters	90	25	4	Shiner.
Unknown	700	Failure.		Do.
Oil Company	1,500	....do....		Hallettsville, 7 miles east.

FAYETTE COUNTY.

Shallow wells.—Water in sufficient quantity for general domestic purposes is found in the northern and western parts of Fayette County at average depths of 60 feet, in the southern part at depths of 75 to 100 feet, and in the eastern part at depths of 40 to 75 feet.

Artesian wells.—There are 20 artesian wells in this county, including a few deep ones; the area in which the greatest number has been drilled lies north of Engle. The average depth of these wells varies from 200 to 300 feet and the maximum flow is 100 gallons a minute. The following is a list of the wells, including their depth, flow, and other data:

Artesian wells in Fayette County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
John Sima	196	25	3	Praha.
Mrs. Vyvjala	216	15	3	Do.
Do	220	50	3	Do.
J. A. Drozd	210	10	3	Do.
J. Kalich	210	18	3	Engle, 2 miles northwest.
M. Schwenke	185	16	3	Do.
J. Sulak	165	10	3	Do.
J. Ladewig	200	10	2	Do.
Compress Co	260	[a] 40	6	Schulenburg.
C. Baumgartner	258	[a] 87	6	Do.
W. A. McKinsen	267	[a] 43	5	Do.
H. P. Schaeffer	300	[a] 79	3	Do.
G. Hoeffers	275	[a] 54	3	Do.
C. Blaschke	300	[a] 79	3	Do.
Southern Pacific R. R	762	(b)	10	Do.

[a] No flow; water rises to number of feet stated below surface of ground. [b] Well caved in.

COLORADO COUNTY.

Shallow wells.—Shallow wells in Colorado County are about 40 feet deep in the northern and western parts, 35 feet in the southern part, and 30 feet in the eastern part. East of Eagle Lake there are a number of wells 30 to 35 feet deep, which furnish a large supply of good water. Two wells supply water for 100 acres of rice, each acre of which requires 9 gallons a minute, and it is generally believed that a good rice well can be obtained at moderate depths in this county at any point east of Eagle Lake.

Artesian wells.—So far as known the only artesian well in Colorad County is located on the west bank of Colorado River at Columbu: This well was bored by the city for water supply, and it has mair tained a steady but small flow for years. The water contains a sma amount of gas. The record of this well is given below:

Record of artesian well at Columbus, Colorado County.

	Feet.
Sand and gravel	0– 29
Soft rock	29– 37
Fine gravel	37– 41
Blue gravel	41– 54
Yellow clay	54– 99
Hard rock	99–101
Yellow clay	101–104
Conglomerate rock	104–110
Yellow clay	110–190
White sand, water bearing	190–198
Yellow clay	198–210
Hard bowlders	210–212
Yellow clay	212–214
Red sandstone	214–220
Yellow clay	220–221
Soft rock	221–223
Yellow clay	223–226
Concrete rock	226–233
Light-red clay	233–280
Bowlder bed	280–281
Yellow clay	281–283
Bowlder rock	283–285
Yellow clay	285–289
Yellow sandstone	289–290
Yellow clay	290–302
Hard sandstone	302–304
White clay	304–309
Red sandstone	309–311
Light-yellow clay	311–319
Yellow sandstone	319–321
Yellow clay	321–412
Slate and clay	412–454
Red, white, and blue clay	454–583
Blue sand; flowing water, 8 gallons a minute	583–600
Hard blue clay	600–620
Fine blue sand; flowing gas	620–633
Shells and old logs	633–637
Blue clay	637–658
White pottery clay	658–675
Fine white sand; flowing water	675–683
Red and blue clay	683–730
Hard rock	730–739
Hard blue clay	739–793
Fine blue sand, hard	793–807
Fine rock (bored into 19 feet).	

AUSTIN COUNTY.

Shallow wells.—A good supply of water is obtained from shallow wells in the western part of Austin County at an average depth of 30 feet; in the southern part at 40 feet, in the eastern part at 60 feet, and in the northern part at about 50 feet.

Artesian wells.—No artesian wells have been reported from this county, although it is probable that they can be obtained along Brazos River.

WALLER COUNTY.

Shallow wells.—In Waller County shallow wells vary in depth from 35 to 50 feet.

Artesian wells.—Only a few artesian wells have been drilled in Waller County, the data of some of which are tabulated below. The most successful free-flowing wells are found near Brazos River.

Artesian wells in Waller County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
Waterworks	1,132	110	4½	Hempstead.
Heber Stone	485	40	1	Hempstead, 5 miles northwest.
Rufus Hardy	850	15	1	Hempstead, 6 miles south.
J. C. Ralston	1,700	.....	.....	Waller, 4 miles south.

WASHINGTON COUNTY.

Shallow wells.—A good supply of excellent water is obtained in Washington County, at various depths, ranging from 20 to 60 feet.

Artesian wells.—Only a few artesian wells have been drilled in this county, a list of which is given below. It is probable that artesian water can be found in the eastern part of the county, in the Brazos bottom lands, but owing to the excellent supply of water from non-flowing wells few attempts have been made to develop artesian water.

A few years ago Heber Stone had a well drilled in Brenham to a depth of 1,500 feet, but no flowing water was obtained. The water rose in the well within 40 feet of the surface, and it is believed that wells penetrating the same water horizon in the Brazos bottom lands would yield flows. The city of Brenham derives its water supply from wells between 300 and 400 feet deep. The following is a list of the artesian wells in this county.

Artesian wells in Washington County.

Owner.	Depth.	Flow.	Diameter.	Location.
	Feet.		*Inches.*	
J. Balbridge	640	Flows...	.....	Gaball, 300 yards northwest.
Robert Moore	240	Flows...	2	Old Washington.
Do	700	Flows...	2	
J. P. Buchanan	500	Strong..	.....	Chapel Hill, 6 miles northeast.
John Carlisle	560	Flows...	.....	Chapel Hill, near.

GRIMES COUNTY.

Shallow wells.—Water from shallow wells is obtained in the eastern part of Grimes County at a depth of 30 feet; in the southern part, at 35 feet; in the western part, along the Navasota, at 30 feet, and in the northern part at depths of 50 to 60 feet.

Artesian wells.—Good artesian water is obtained in and around Navasota and between Navasota and Brazos River. The following table shows the artesian wells of Grimes County:

Artesian wells in Grimes County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
R. A. Sangster	300	60	2	Navasota.
A. J. Sangster	225	+15	.....	Navasota, ½ mile south.
Ice factory	250	+20	6	Navasota.
Mrs. Lewis Wilson	224	.....	.....	Do.
August Horst	1,000	.....	.....	Do.
City waterworks	97	.....	.....	Do.
Shumaker	101	.....	.....	
J. M. McCord	850	Strong.	4	Courtney, ½ mile southeast.
Do	900	Medium.	4	Courtney, ½ mile east.

Record of Navasota well, Grimes County.

	Feet.
Soil	0– 2
Clay	2– 18
Sand	18– 29
Blue clay	29– 94
Slate	94–114
Blue clay	114–216
Rock	216–220
Water sand	220–237
Blue shale	237–277
Rock	277–280

Analysis of water from deep well at Navasota, Grimes County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	140.0	Carbonate radicle (CO_3)	168.
Magnesium (Mg)	8.8	Sulphates of iron and aluminum	15.
Calcium (Ca)	43.0	Organic matter	38.
Chlorine (Cl)	79.0		——
Sulphate radicle (SO_4)	41.0		532.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

LIBERTY COUNTY.

Shallow wells.—Water from shallow wells is secured throughout Liberty County at depths of 15 to 25 feet.

Artesian wells.—The Gulf, Colorado and Santa Fe Railroad has deep wells at Trinity River and Cleveland. Records of these wells and analyses of their waters are given below. The following table contains a list of flowing artesian wells drilled in Liberty County:

Flowing artesian wells in Liberty County.

Owner.	Depth.	Diameter.	Distance and direction from Liberty.
	Feet.	*Inches.*	
J. T. Russell	290	.....	½ mile south.
Do	300	.....	½ mile southeast.
Southern Pacific R. R	800	.....	300 yards southeast.
Fisher	150	.....	1 mile west.
Melon farm	240	.....	½ mile south.
Do	245	.....	Do.
Texas and New Orleans R. R	576	6	

Record of deep well at Trinity River, Liberty County.

	Feet.
Red clay	0– 8
Sand	8– 38
Clay	38– 60
Rock and clay	60–104
Quicksand	104–117
Rock	117–119
Clay	119–121
Rock	121–133
Clay	133–145
Rock	145–151
Coarse sand	151–163
Soapstone	163–194
Rock	194–196
Sand	196–203
Rock	203–210
Clay	210–220
Rock	220–240
Water sand	240–290
Clay	290–300

Analysis of water from deep well at Trinity River, Liberty County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	19.0	Carbonate radicle (CO_3)	7.0
Magnesium (Mg)	4.4	Silica (SiO_2)	14.0
Calcium (Ca)	38.0	Organic matter	50.0
Chlorine (Cl)	16.0		
Sulphate radicle (SO_4)	20.0		305.4
Bicarbonate radicle (HCO_3)	137.0		

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

Record of deep well at Cleveland, Liberty County.

	Feet.
Soil	0– 4
Yellow clay	4– 24
Yellow sand	24–100
Clay	100–108
Sand	108–131
Rock	131–132
Clay and coarse sand	132–140
White sand rock	140–142
Yellow clay	142–160
White sand rock	160–161
Yellow sand	161–165
White sand rock	165–166
Yellow clay	166–236
Sand	236–246
Clay	246–288
Open water sand	288–367
Rock	367–368

Analysis of water from deep well at Cleveland, Liberty County.[a]

[Analyst, W. A. Powers.]

	Parts per million.		Parts per milli
Silica (SiO_2)	27	Chlorine (Cl)	9
Calcium (Ca)	43	Organic matter	3:
Magnesium (Mg)	30	Total solids	34
Sodium (Na)	12		
Carbonate radicle (CO_3)	74	Free carbonic acid (CO_2)	1
Sulphate radicle (SO_4)	113	Carbonic acid combined as HCO_3	6

MONTGOMERY COUNTY.

Shallow wells.—Shallow wells in Montgomery County vary in dep from 30 to 50 feet.

Artesian wells.—The Gulf, Colorado and Santa Fe Railroad has deep well at Bobbin and an artesian well at Conroe. Records of the wells and analyses of their waters are given below.

Record of well at Bobbin, Montgomery County.

	Feet.
Soil	0– 2
Clay	2– 12
Sand	12– 28
Clay	28– 78
Quicksand	78– 90
Sandstone	90–101
Clay	101–114
Water sand	114–134
Clay	134–234
Sand	234–264
Rock	264–309
Clay	309–343

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts p million and ionic form at U. S. Geol. Survey.

	Feet.
Rock	343–347
Slate	347–383
Rock	383–390
Slate	390–454
Rock	454–457
Slate	457–480

Analysis of water from deep well at Bobbin, Montgomery County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	90	Carbonate radicle (CO_3)	65
Magnesium (Mg)	14	Silica (SiO_2)	27
Calcium (Ca)	110	Sulphates of iron and aluminum	27
Chlorine (Cl)	167	Organic matter	70
Sulphate radicle (SO_4)	11		939
Bicarbonate radicle (HCO_3)	358		

Record of well at Conroe, Montgomery County.

	Feet.
Red clay	0– 12
Rock	12– 13
Red clay	13– 69
Sand	69– 89
Red clay	89– 133
Hard yellow clay	133– 153
Joint clay	153– 182
Water sand	182– 193
Soft clay	193– 248
Hard clay	248– 265
Rock	265– 267
Hard clay	267– 280
Rock	280– 285
Dry sand bed	285– 297
Clay	297– 340
Rock	340– 343
Clay	343– 363
Rock	363– 365
Blue clay	365– 489
Light clay	489– 500
Soft clay	500– 575
Rock	575– 577
Water sand	577– 642
Blue clay	642– 680
Water sand	680– 740
Clay	740– 790
Soapstone	790– 831
Red clay	831– 888
Soapstone	888– 924
Clay	924– 976
Rock	976– 978
Clay	978–1,003

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

	Feet.
Rock	1,003–1,004
Sand	1,004–1,008
Red clay	1,008–1,033
Soapstone	1,033–1,073
Rock	1,073–1,075
Sand	1,075–1,125
Soapstone	1,125–1,169
Rock	1,169–1,170
Clay	1,170–1,190
Rock	1,190–1,192
Clay	1,192–1,212
Sand	1,212–1,234
Rock	1,234–1,236

Analysis of water from deep well at Conroe, Montgomery County. [a]

	Parts per million.		Parts per million.
Sodium (Na)	41	Silica (SiO_2)	21
Magnesium (Mg)	16	Organic matter	38
Calcium (Ca)	73		407
Chlorine (Cl)	48		
Carbonate radicle (CO_3)	170		

WALKER COUNTY.

Shallow wells.—Water is procured from shallow wells in Walker County at depths varying from 35 to 45 feet.

Artesian wells.—There are no artesian wells in Walker county, but it is believed that they could be obtained throughout its area. The numerous flowing streams in the county and the shallow depths at which nonflowing wells may be obtained have decreased the demand for artesian water.

SAN JACINTO COUNTY.

Shallow wells.—In San Jacinto County shallow wells vary in depth from 35 to 60 feet.

Artesian wells.—There are no artesian wells in this county. At Oakhurst, 7 miles east of Dodge, a well was drilled to a depth of 1,052 feet, penetrating hard rock the greater part of the distance, but no flowing water was obtained. It is generally believed that the prospects for artesian water in this region are very poor.

POLK COUNTY.

Shallow wells.—The average depth of shallow wells in Polk County is 30 feet.

Artesian wells.—There is little demand for artesian water in Polk County, owing to the numerous small flowing streams and the shallow depths at which nonflowing wells may be obtained.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey

HARDIN COUNTY.

Shallow wells.—The shallow wells of Hardin County vary in depth from 15 to 30 feet. The county is well drained by the small flowing streams that empty into Neches River or Pine Island Bayou.

Artesian wells.—In this county there is little need for artesian water and consequently no artesian wells have been drilled. Deep wells are owned by the Santa Fe Railroad at Silsbee, Dies (Kountze post-office), and Votaw. Records of these wells and analyses of their waters are given below.

Record of well at Silsbee, Hardin County.

	Feet.
Clay and sand	0– 88
Sand	88–288
Blue sand	288–374
Yellow clay	374–392
Water sand	392–466
Clay	466–468

Analysis of water from deep well at Silsbee, Hardin County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	24.0	Carbonate radicle (CO_3)	9.5
Magnesium (Mg)	5.9	Silica (SiO_2)	19.0
Calcium (Ca)	36.0	Organic matter	44.0
Chlorine (Cl)	26.0		315.4
Sulphate radicle (SO_4)	15.0		
Bicarbonate radicle (HCO_3)	136.0		

Record of deep well at Dies, Hardin County.[a]

	Feet.
Soil	0– 3
Clay	3– 18
Dry sand	18– 66
Dark clay	66– 75
Water sand	75–268

Analysis of water from deep well at Dies, Hardin County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	33.0	Silica (SiO_2)	45.0
Calcium (Ca)	59.0	Sulphates of iron and aluminum	7.2
Chlorine (Cl)	62.0	Organic matter	37.0
Sulphate radicle (SO_4)	2.2		324.4
Carbonate radicle (CO_3)	79.0		

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

Record of well at Votaw, Hardin County.

	Feet.
Clay	0–18
Sand	18–168
Coarse sand	168–203
Fine sand	203–226
Coarse sand	226–260
Clay	260–265
Open water sand	265–320
Clay	320–354
Rock	354–355

Analysis of water from deep well at Votaw, Hardin County.[a]

	Parts per million.		Parts per million.
Sodium (Na)	2.7	Sulphates of iron and aluminum	10.0
Calcium (Ca)	13.0	Organic matter	39.0
Sulphate radicle (SO_4)	5.8		111.5
Carbonate radicle (CO_3)	19.0		
Silica (SiO_2)	22.0		

TYLER COUNTY.

Shallow wells.—In the southern part of Tyler County the wells are about 20 feet deep, in the eastern part about 25 feet, in the northern part about 80 feet, and in the western part about 65 feet.

Artesian wells.—No attempts to obtain artesian water have been made in this county, but an oil well was drilled near Woodville to a depth of 933 feet without finding artesian water.

JASPER COUNTY.

Shallow wells.—Shallow wells in Jasper County vary in depth from 20 to 50 feet.

Artesian wells.—So far only three artesian wells have been reported from this county, and these are all located on the ranch of Wiess & Sanders, near Wiess Bluff, in the southern part of the county. Various data concerning these wells are given below. There is a deep well at Kirbyville, a record of which follows, also an analysis of its water.

Artesian wells in Jasper County.

Owner.	Depth.	Flow per minute.	Location.
	Feet.	*Gallons.*	
Wiess & Sanders	1,062	.....	Wiess Bluff, 2¼ miles north 6° east.
Do	1,054	45	3 miles north 8° east.
Do	1,070	60	2½ miles north 7° east.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geological Survey.

Record of Wiess & Sanders artesian well No. 1, Jasper County.[a]

	Feet.	
Fine sandy loam	0–	2
Red clay	2–	25
White sand	25–	75
Yellow clay	75–	96
Fine blue sand	96–	129
Yellow clay	129–	156
White sand	156–	173
Yellow clay	173–	225
Fine blue sand	225–	252
Hard yellow clay	252–	386
White sand	386–	476
Blue clay	476–	547
Blue sand	547–	569
Hard blue clay	569–	579
Coarse white sand	579–	628
Blue clay	628–	646
Fine blue clay	646–	676
Hard blue clay	676–	695
Coarse white sand	695–	750
Hard blue clay	750–	759
Soft blue clay	759–	784
White sand	784–	794
Hard blue clay	794–	814
Fragmentary sand	814–	818
Hard blue clay	818–	900
Rotten sandstone	900–	906
Blue clay	906–	913
White sand	913–	935
Hard blue clay	935–	1,002
Coarse white sand	1,002–	1,021
Fine gravel	1,021–	1,038
Coarse gravel	1,038–	1,052
White sand	1,052–	1,086
Blue clay	1,086–	1,104
White sand	1,104–	1,202

Record of Wiess & Sanders artesian well No. 2, Jasper County.

	Feet.	
Fine sandy loam	0–	2
Yellow clay	2–	6
Yellow sand	6–	18
Gray clay	18–	27
White sand	27–	50
Yellow clay	50–	83
Fine blue sand	83–	117
Blue clay	117–	152
White sand	152–	173
Blue clay	173–	234
Fine blue sand	234–	264
Blue clay	264–	295
Fine blue sand	295–	356
Gray clay	356–	426

[a] Capacity of this well is 165 gallons a minute, or 237,000 gallons every twenty-four hours.

	Feet.
White sand	426– 520
Blue clay	520– 583
Fine blue sand	583– 620
Blue hard clay	620– 631
Coarse white sand	631– 684
Blue clay	684– 697
Fine blue sand	697– 718
Soft stone	718– 756
Hard blue clay	756– 768
Coarse white sand, loses water rapidly	768– 799
Hard blue clay	799– 853
Unable to tell the strata, drills like oil strata	853– 868
Hard blue clay	868– 936
Fine blue clay	936 949
Hard blue clay	949 990
White sand	990–1,012
Blue and green clay	1,012–1,039
Hard blue clay.	

Record of deep well at Kirbyville, Jasper County.

	Feet.
Yellow clay	0– 17
Yellow sand	17– 34
Coarse white sand	34– 54
Sand and gravel	54– 82
Water sand	82–212
Blue clay	212–227

Analysis of water from deep well at Kirbyville, Jasper County.[a]

	Parts per million.
Magnesium (Mg)	9.2
Chlorine (Cl)	2.5
Carbonate radicle (CO_3)	21.0
Sulphates of iron and aluminum	15.0
	47.7

NEWTON COUNTY.

Shallow wells.—The average depth of wells in Newton County is 35 feet, the deepest one being in the northern part.

Artesian wells.—The only artesian well in this county is located near Call and is owned by the Kirby Lumber Company. This well is 796 feet deep, 4 inches in diameter, and has a flow of 38 gallons a minute. Several oil wells have been drilled near this place, but no artesian flows have been obtained.

WEBB COUNTY.

Shallow wells.—The shallow wells of Webb County vary considerably in depth. In the western part they have an average depth of 60 feet; in the northern part, 425 feet; and in the eastern part, 375 feet. It is very difficult to obtain water in the southern part of the county.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geological Survey.

Artesian wells.—At Bruniville, a station on the Texas Mexican Railway, four artesian wells were drilled for A. M. Bruni. They are each 325 feet deep and flow only about 3 gallons a minute. They are located on 1 acre of land, just south of Bruniville, within 100 feet of the railroad track.

MAVERICK COUNTY.

Shallow wells.—It is difficult to find water in Maverick County. In the northern part one well was drilled to a depth of 918 feet without getting water, while wells in other localities 500 feet deep yielded salty water.

Artesian wells.—So far as can be ascertained there are no artesian wells in Maverick County.

DIMMIT COUNTY.

Shallow wells.—In the Nueces Valley good wells are obtained at moderate depths, but on the higher lands they vary from 100 to 150 feet in depth.

Artesian wells.—There are over 60 artesian wells in Dimmit County, ranging in depth from 300 to 700 feet. The water is used for both stock and irrigation purposes. The following is a list of the artesian wells of this county, with depth, flow, and other data concerning them:

Artesian wells in Dimmit County.

Owner.	Depth.	Flow.	Diameter.	Distance and direction from Carrizo Springs.
	Feet.	*Gallons.*	*Inches.*	
F. M. Shaw	350–400	150	3½	2½ miles north.
Do		150	3½	Do.
Do		Weak.	3½	5 miles northwest.
Do		Weak.	3½	5 miles east.
J. J. Webb	500	150	4	Do.
Thos. Paterson	600	200	5⅝	4 miles east.
Do	650	200	8	Do.
A. Eardley	590–690	1,400	10	5½ miles east.
Do		1,400	10	Do.
Do		1,400	10	Do.
W. A. Mance	600	100	6¼	4 miles east.
Do	600	No flow.	6¼	Do.
J. L. Hudson	500	150	6	2 miles northeast.
M. J. Dermann (5 wells)	350	125	4	3 miles north.
Do	400	150	5⅜	Do.
J. C. Owen	350	150	6½	2½ miles north.
Burton	315	125	5⅝	2 miles north.
Do	375	125	5⅝	Do.
W. L. Kendall	350	150	5⅝	3 miles north.
Do	350	Weak.	5⅝	Do.
J. K. Rector	600	200	5⅝	5 miles east.
M. L. Oppenheimer	350	125	5⅝	1 mile northeast.
George & Wilkerson	600	100	5⅝	1 mile north.
F. Moehrig (3 wells)	350–600	[a] 150	5⅝	2½ miles north.
W. B. Rector	382	200	8	Do.
Couran & Jeffrey	350	100	5⅝	Do.
Craig	325	50	4½	½ mile east.
Hugh Knight	600	350	8	5 miles southeast.
Chas Pollard	600	350	10	Do.
A. Richardson (8 wells)	600–650	100–600	4–12	6–10 miles southeast.
Ed. Schimmelphening & Bro. (2 wells)	600	150, 200	5⅜	6 miles southeast.
McCaleb & McDaniel (3 wells)	400	125–150	5⅜	5 miles southeast.
Shipp (2 wells)	325, 418	100	5⅝	4½ miles southeast.
T. A. Coleman (2 wells)	300	50, 75	5⅜	5 miles south.
G. White	350	125	5⅝	10 miles northwest.
Tom Riggs	350	125	5⅜	Do.
T. A. Coleman	350	125	5⅝	Do
F J Arnold	500	150	8⅝	5 miles southeast.
Wm George	350	20	4½	5½ miles southeast.
Bob Lemons (2 wells)	350, 700	No flow.	6½	6 miles southwest.

[a] Each.

Record of Eardley Barosa Creek well, Dimmit County (near Carrizo Springs).

	Feet.
Light red soil and clay	0– 3
Pale blue clay	3– 9
Sand and yellow clay	9– 34
Yellow clay	34– 64
Pale to dark-blue clay	64– 99
Sandstone, a little salt water, no flow	99–102
Sticky pale-blue clay	102–152
Blue clay containing small seams of coal	152–252
Sand and clay	252–297
Fine-grained sandstone	297–312
Sand and clay	312–332
Blue clay	332–377
Darker blue clay	377–417
Sand and clay	417–462
Fine sand rock. Small flow	462–522
Sandstone; flow gradually increased	522–682
Fine sand and clay	682–720

ZAVALLA COUNTY.

Shallow wells.—Water from shallow wells is obtained in the western part of Zavalla County at an average depth of 50 feet, in the southern part at a depth of 75 feet, and in the eastern and northern parts at a depth of 100 feet.

Artesian wells.—Artesian wells have been drilled in the western and southwestern parts of the county along some of the tributaries of Nueces River. The following list of wells and data concerning them were furnished by George C. Hermann, of Batesville.

Artesian wells in Zavalla County.

Owner.	Depth.	Flow.	Diameter.	Distance and direction from Batesville.
	Feet.		*Inches.*	
R. R. Ware	211		5	31 miles south 56° west.
Ed. English	450		5	28½ miles south 46° west.
Do	450		5	28½ miles south 46° west.
Jas. Oden	400		5	29 miles south 49° west.
B. H. Erskine	250		5	30 miles south 50° west.
N. Y. and T. L. Co	400		5	25 miles south 58° west.
Do	450		5	25 miles south 66° west.
J. C. Turman	450	Slight.	5	28 miles south 71° west.
Ed. English	390	Strong.	6	28 miles south 47° west.
Do	410	Strong.	6	28 miles south 46° west.
James Oden	500	Strong.	6	28½ miles south 48° west.
B. H. Erskine	420	Strong.	6	30 miles south 50° west.
Clift	450	Strong.	6	27½ miles south 47° west.
C. Vancleve	310	Strong.	6	28 miles south 53° west.
Brown & Williams	560	Strong.	6	26 miles south 51° west.
T. A. Coleman (4 wells)	450-460	Strong.	6	31 miles south 49° west.
A. Boynton	460	Strong.	6	29 miles south 46° west.
Pratt & Hays	900	Slight.	10	25 miles south 40° west.
I. T. Pryor	1,029	(a)	10	16 miles south 70° west.
T. Riggs	420	Flows.	6	28 miles south 45° west.
A. Boynton	460	Flows.	6	29 miles south 46° west.
T. A. Colemnn	460	Strong.	6	31 miles south 49° west.
R. R. Ware	260	Strong.	6	32 miles south 56° west.

a Water rises within 10 feet of surface.

LASALLE COUNTY.

Shallow wells.—In Lasalle County the pump wells are considerably deeper than those in adjoining localities. They vary from 150 to 200 feet in depth.

Artesian wells.—There are 27 artesian wells in this county. The area of greatest development in well boring is around Artesia, where a number of wells are utilized for irrigation purposes. They vary in depth from 200 to 500 feet and usually furnish a strong flow of good water. At Cotulla the International and Great Northern Railroad has drilled a well 1,008 feet deep, but the water is slightly impregnated with salts of magnesia. In the vicinity of Dull's ranch, in the northeastern portion of the county, along Frio River, there is a well-developed artesian district. The following is a list of the artesian wells of the county:

Artesian wells in Lasalle County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Meters.*	
International and Great Northern R. R.	900	6	.....	Cotulla.
Do	1,008	.....	.....	Do.
J. W. McInnis	486	15	.....	Do.
Joe Cotulla	400	4	.....	Cotulla, 1½ miles north.
A. Armstrong	764	2	.....	Cotulla, 8 miles west.
J. M. Ramsey	550	24	6	Artesia, 2 miles northeast.
Do	550	24	6	Do.
Do	350	15	6	Do.
Do	350	8	6	Artesia, 1 mile northeast.
Do	186	5	6	Artesia, ½ mile northeast.
J. W. Bucow	400	20	6	Artesia, 4 miles east.
W. H. McWhorter	450	10	6	Artesia, 1 mile south.
Kuhn	600	10	6	Artesia, 6 miles east.
Anderson & Sinclair	670	10	8	Artesia, 1 mile northwest.
Do	670	10	8	Artesia, ½ mile northeast.
Crossley	400	10	6	Artesia, 1 mile southeast.
C. H. DeRyle	450	10	6	Artesia, 1½ mile southeast.
T. J. Alderman	180	0	.....	Artesia, 3 miles northeast.
Do	650	0	.....	Do.
Naylor & Jones	295	4	6	Dull's ranch, 2 miles east.
Do	366	4	6	Dull's ranch, 7 miles east.
Do	720	30	6	Dull's ranch, 14 miles northeast.
Do	310	12	6	Dull's ranch, 3 miles east.
Do	300	4	6	Dull's ranch, 7 miles northeast.
W. C. Irwin	797	100	.....	Dull's ranch, 7 miles northwest.
Uhl & Gaith	767	4	1	Cotulla, northwest.
International and Great Northern R. R.	800	0	.....	Encinal.

McMULLEN COUNTY.

Shallow wells.—The nonflowing wells of McMullen County are generally deep. In the eastern part they have an average depth of 130 feet, in the northern part 250 feet, and in the southern part 350 feet. No information has been received concerning the depth of wells in the western part of the county.

Artesian wells.—Data have been obtained of seven artesian wells in McMullen County. A list of these wells, with their depth, flow, size, and approximate location is given below:

Artesian wells in McMullen County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
County	485	.....	4	Public square, Tilden.
Ortho Askey	300	.....	.....	Tilden, 12 miles east.
Do	147	5	.....	Tilden, 13 miles east.
Sam Crowther	1,728	250	.....	Tilden, 14 miles northeast.
Do	1,325	200	.....	Do.
Naylor & Jones	700	15	6	Tilden, 20 miles west.
Do	512	15	6	Do.

FRIO COUNTY.

Shallow wells.—Water is obtained from shallow wells in Frio County at depths of 60 to 125 feet.

Artesian wells.—There are flowing wells along San Miguel Creek, also at Derby, and northwest of Derby along Frio River. A typical artesian well of Frio County is shown on Pl. I, *B* (p. 1). Many of the wells along San Miguel Creek are located along the creek bed, on very low ground; most of them are about 400 feet in depth, 8 inches in diameter, and flow about 10 gallons a minute. The general distribution of these wells is shown in Pl. II (p. 2), and their depth, size, flow, and approximate location are given in the following table:

Artesian wells in Frio County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
G. F. Hinds	420	25	.....	San Miguel Creek, 1¼ miles from Atascosa County line.
Do	410	15	.....	Do.
Do	400	20	.....	Atascosa County, 4 miles north of No. 2.
F. M. O'Connor	405	50	5	San Miguel Creek, 1 mile above No. 1.
Do	200	17	4	San Miguel Creek, 1 mile above No. 4.
Do	115	12	2	San Miguel Creek, 2 miles above No. 5.
Do	60	7	1	San Miguel Creek, 2 miles above No. 6.
Do	300	20	4	1 mile south of No. 4.
S. Speed	.....	.....	.....	Derby, 4 miles east.
Do	.....	.....	.....	Do.
P. E. Authar	600	.....	6	Pearsall, 4 miles north.
Halff & Schremer	800	.....	5	Pearsall, 6 miles southwest.
Do	1,473	400	5	Pearsall, 4 miles south.
Keystone Land and Cattle Co	.....	10	8	San Miguel Creek, 4 miles above No. 7.
Do	.....	10	8	San Miguel Creek, 3 miles above No. 14.
Do	398	10	8	San Miguel Creek, 3 miles above No. 15.
Do	.....	10	8	San Miguel Creek, 4 miles above No. 16.
Do	.....	2	8	San Miguel Creek, 1 mile west of No. 17.
Do	.....	10	8	San Miguel Creek, 4 miles above No. 17.
.....	.....	5	8	San Miguel Creek, 1 mile below No. 6.
.....	380	12	6	Miguel, 5 miles west of post-office.
.....	648	.....	8	2 miles south of No. 18.
J. W. De Villbis	125	19	2	San Miguel Creek, ½ mile above No. 6.

ATASCOSA COUNTY.

vells.—A good supply of excellent water is obtained from 60 feet deep throughout the greater part of Atascosa

wells.—Artesian water is found in all parts of this county, arying from 200 to 700 feet. The county is well drained ıtaries of San Miguel Creek, and wells for the most part are ıg these tributaries. The approximate location of artesian heir depth, flow, and diameter are given in the following

Artesian wells in Atascosa County.

Owner.	Depth.	Flow per minute.	Diameter.	Distance and direction from Pleasanton.
	Feet.	*Gallons.*	*Inches.*	
.....	120	20	.....	1 mile east.
.....	520	10	.....	Do.
.....	447	30	.....	8 miles south.
.....	376	7	.....	Do.
.....	620	32	.....	Do.
.....	625	.....	.....	11 miles southwest.
d Great Northern R. R.....	740	20	.....	20 miles southwest.
.....	400	5	.....	19 miles southwest.
.....	314	60	.....	4 miles northeast.
.....	230	4	.....	4 miles north.
.....	500	40	.....	In town.
.....	340	15	.....	Do.
.....	320	6	.....	7 miles southeast.
.....	510	.....	.....	6 miles northeast.
.....	397	.....	.....	5 miles east.
.....	337	30	.....	Do.
.....	227	50	.....	3 miles east.
.....	430	10	.....	4 miles southeast.
.....	319	15	.....	3 miles northwest.
.....	300	2	.....	6 miles northwest.
.....	240	12	.....	5 miles northwest.
.....	228	4	.....	4 miles northeast.
.....	208	8	.....	Do.
.....	308	55	4	6 miles northeast.
.....	540	60	3½	5 miles east.
.....	915	.....	.....	8 miles northeast.
.....	700	.....	.....	12 miles northeast.
.....	1,011	.....	.....	11 miles east.
.....	207	.....	.....	8 miles southeast.
.....	441	35	2	19 miles southeast.
.....	139	4	.....	16 miles southeast.
.....	165	6	.....	Do.
.....	340	4.5	.....	12 miles southeast.
.....	202	4.5	.....	13 miles southeast.
.....	200	4.5	.....	12 miles southeast.
.....	729	40	.....	6 miles south.
.....	700	35	.....	4 miles south.
.....	525	75	.....	14 miles south.
.....	280	12	.....	18 miles southeast.
.....	378	.....	.....	In town.
ce.....	377	30	.....	Do.
.....	357	18	.....	Do.
.....	368	.....	.....	Do.
.....	406	4	.....	Do.
.....	301	5	.....	2½ miles northeast.
.....	497	40	2	In town.
.....	700	100	4	Do.

BEXAR COUNTY.

vells.—In the southern part of Bexar County water can be depths varying from 30 to 60 feet; near Vanraub, at a 5 feet, and at Leon Springs, at depths of 40 to 200 feet.

vells.—There are nearly 100 artesian wells in Bexar County. m are among the strongest wells in the State. The water

is of excellent quality and is used largely for irrigation. The followi is a list of the artesian wells, giving location and other data:

Artesian wells in Bexar County.

Owner.	Depth.	Flow per minute.	Location with respect San Antonio.
	Feet.	*Gallons.*	
West End Town Co.	260	150	West End Lake.
Russ	250	60	In town.
Brendle	583	.....	3 miles north.
Yantis	540	400	2.5 miles northwest.
Waterworks No. 1	630	1,042	¼ mile below head of ri
Waterworks No. 2-4	780	[a] 1,042	1¼ miles below head of r
Waterworks Nos. 5-8 [b]	880	[a] 4,166	Market street.
Waterworks Nos. 9-12 [c]	880	[a] 1,740	Do.
Schulz Sanitarium	712	555	Alamo Plaza.
Crystal Ice Co.	657	417	Eighth street.
Do.	657	417	Do.
Do.	715	278	Do.
Do.	850	36	Do.
Street railway	980	156	Tenth street.
Do.	1,140	17	Do.
Court-house [d]	760	861	Center of city.
State asylum [e]	1,900	Flows.	3 miles southeast.
Col. Terrell [e]	1,900	555	5 miles southeast.
C. Kampman	650	200	3 miles east.
Do.	464	20	Do.
Geo. Dulnig [f]	2,215	1,007	6 miles southeast.
Santa Rosa Hospital	1,000	104	400 yards northwest c house.
Do.	1,250	.....	Do.
Schulz	822	200	2½ miles northwest.
Union Meat Co.	1,202	300	1½ miles southwest.
Menger Hotel	1,160	170	
Koelbeen	1,100	140	Southern Pacific r house.
Dignowitty	465	55	1½ miles west.
Kampman	850	200	Vellta street.
Epps	884	70	2½ miles southwest.
Van Dale	835	55	2 miles west.
F. F. Collins	700	1,200	¼ mile southwest.
Do.	850	300	¼ mile northeast.
T. F. Brady	1,500	400	2½ miles southwest.
Walters	900	200	Do.
Barnes	950	1,200	Do.
Meerscheidt-Stieren Irrigation Co. [g]	950	800	3 miles west.
A. Herff	1,200	Slight.	3½ miles west.
Elmendorf	750	377	3 miles west.
Hofheinz	.....	.....	5 miles southwest.
Tommins	1,500	Slight.	2½ miles south.
Acme Irrigation Co.	1,200	No flow.	5 miles southwest.
J. D. Guinn	610	50	3 miles northeast.
H. J. Ackerman	1,400	50	6 miles east.
Watters	1,400	50	2½ miles southwest.
D. Sullivan	800	No flow.	3 miles northwest.
J. C. Chaney	1,500	100	2½ miles southeast.
City brewery	728	2,083	James street.
Do.	728	2,083	Do.
Lone Star Brewery	805	650	Jones street.
United States Ice Plant	710	650	Grayson street.
Do.	710	650	Do.
D. Meyer	.....	.....	3 miles west.
Tappans polo ranch	.....	.....	5 miles northwest.
J. D. Guinn	1,000	No flow.	5½ miles northeast.
T. B. Dashiel	635	Slight.	7 miles northeast.
W. Eisenhauer	700	....do....	5 miles east.
Urbahn	1,200	No flow.	4 miles east.
Kampman [h]	1,000	Occasional.	3 miles north.
St. Louis College	720	No flow.	5 miles west.
Do.	720	....do....	Do.
International and Great Northern R. R. [i]	808	Good.	At Davenport.

[a] Each.
[b] Four 12-inch wells.
[c] Four 8-inch wells.
[d] Gas and water at 460 and 620 feet below surface.
[e] Hot sulphur water.
[f] 6-inch well yielding hot sulphur water.
[g] Two wells: One 6-inch, with 800-gallon flow; one 10-inch, with 3,000-gallon flow.
[h] Water at 630 feet.
[i] Water rises within 110 feet of surface.

WILSON COUNTY.

wells.—The shallow wells of Wilson County are from 30 to eep.

wells.—There are two principal artesian-well districts in y—one in the southwestern part, where a group of wells by J. S. Thornton and J. J. Stevens, and one in the vicinity le and Sutherland Springs. A list of these wells, including lata, is given below.

Artesian wells in Wilson County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
.....	565	20	.....	Union, ½ mile northeast.
.....	700	15	2½	Floresville, 8 miles southwest.
.....	840	90	4	Floresville, 11 miles south, 4 west.
.....	460	30	3	Floresville, 8 miles south, 7 west.
.....	365	40	.....	Floresville, 10 miles west, on Borego Creek.
.....	650	50	.....	Floresville, 11 miles southwest, on Borego Creek.
.....	650	50	.....	Floresville, 10½ miles northwest, on Borego Creek.
.....	1,036	50	.....	Floresville, 13 miles southwest, on Prietas Creek.
.....	960	50	.....	Floresville, 16 miles southwest, on Lucas Creek.
n.....	700	15	3½	Floresville, 4 miles west.
.....	480	12	2½	Floresville, 5 miles west.
.....	1,200	.....	.....	Sutherland Springs, ½ mile northeast.
.....	400	00	.....	Sutherland Springs, 3 miles southeast.

GUADALUPE COUNTY.

wells.—Water is obtained in Guadalupe County in the east- t an average depth of 40 feet, in the southern part at 60 western part at 70 feet, and in the northern part at 80 feet.

wells.—The only attempt to develop the artesian-water of this county was made by Adolph Ziegenhols, on his farm orth of Seguin, where a flow of strong sulphur water was depth of 800 feet.

CALDWELL COUNTY.

wells.—Good wells are obtained throughout the greater ldwell County at depths varying from 18 to 50 feet. Near wells are from 18 to 20 feet deep, but on the prairie west rt they are somewhat deeper. South of Maxwell and east ale it is difficult to get water, and it is generally not obtained less than 100 feet.

Artesian wells.—Only two artesian wells have been reported from this county. T. F. Hudson, near Lockhart, has a 6-inch flowing well 260 feet deep, and V. Leshikar has one 5 miles west of Lockhart which has a depth of 180 feet, a diameter of 8 inches, and a flow of only a few gallons a minute.

BASTROP COUNTY.

Shallow wells.—Throughout Bastrop County the shallow wells are from 35 to 70 feet deep and generally furnish a good supply of water.

Artesian wells.—Very little prospecting has been done for artesian water in this county. In 1893 a well was drilled to a depth of 1,010 feet near Bastrop by the Bastrop Building and Loan Association without striking water.

LEE COUNTY.

Shallow wells.—In Lee County the average shallow well is 40 to 50 feet deep, and a good supply is usually obtained.

Artesian wells.—Owing to the ease with which shallow wells may be obtained in this county, few attempts have been made to develop artesian water. The only flowing well in the county is owned by M. G. York, near Leobau. It is a 6-inch well, 800 feet deep, but the exact flow has not been ascertained.

ROBERTSON COUNTY.

Shallow wells.—A good supply of water is found in Robertson County about 40 feet below the surface.

Artesian wells.—There are a large number of flowing wells between Big and Little Brazos rivers, from a point opposite Calvert to the mouth of the Little Brazos, a distance of about 25 miles. Water is obtained throughout this valley at four artesian horizons at depths of 160, 450, 650, and 920 feet. Attempts to get water east of Hearne, on the highland extending from Bremond to Franklin, have resulted in failure. At Hearne there are 23 flowing wells, nearly all of which obtain water from an artesian horizon 700 feet below the surface. The following is a list:

Artesian wells at Hearne.

Owner.	Depth.	Owner.	Depth.
	Feet.		*Feet.*
. Creanan	740	L. W. Carr	700
Do	680	C. J. Hostrasses	690
ouston and Texas Central R. R	720	R. C. Allen	666
Do	720	Mrs. H. K. Davis	710
ompress	700+	Chas. Wood	400
in and Light Co	700+	W. P. Ferguson	720
Do	700	J. H. Hartzog	720
ational Oil Co	715	C. L. Glass[b]	690
lanters' O l Co	660	Do	700
tock Yards[a]	1,020	Do	710
Do	750	City	720
N. Kerlicks	700		

[a] One mile northwest of Hearne. [b] Three miles southwest of Hearne.

MILAM COUNTY.

Shallow wells.—The average depth of shallow wells throughout Milam County is 50 feet. An abundant supply is usually obtained. In the western part of the county considerable difficulty is sometimes experienced in getting a successful well.

Artesian wells.—The International and Great Northern Railroad drilled a 6-inch well at Thorndale to a depth of 2,000 feet, passing through several beds of lignite coal, without obtaining artesian water. Other similar deep borings have been made for artesian water in the western part of the county without success. The following is a list of deep borings in Milam County:

Deep borings in Milam County.

Owner.	Depth.	Location.
	Feet.	
W. S. Caruthers	1,790	Thorndale.
A. E. Brady	1,356	Maysfield.
T. J. Estes	831	Baileyville, 3½ miles west.
A. J. Raymond	700	Branchville.
J. A. Peele	530	Branchville, 4 miles east.

BURLESON COUNTY.

Shallow wells.—In Burleson County wells 50 to 75 feet deep furnish a good supply of water.

Artesian wells.—Flowing wells are obtained in the Brazos bottom lands at depths varying from 355 to 1,250 feet, the average being about 700 feet. A list of these wells, with other data, the record of a 688-foot well at Clay, and analyses of the water from this well and from one of M. Parker's wells are given below:

Artesian wells in Burleson County.

Owner.	Depth.	Flow per minute.	Diameter.	Location.
	Feet.	*Gallons.*	*Inches.*	
J. W. Coulter	750	10	1¼	Clay, 6 miles northeast.
Do		Small.	1	Clay, 7½ miles northeast.
Carson & Smith	355	5	1	Clay, 8 miles northeast.
Do	750	Strong.	1	Do.
T. R. Batte[a]	850	50	1¼	Whittaker, 3½ miles southeast.
J. O. Chance	900	1½	2	Whittaker, 1½ miles northeast.
Do.[b]	1,009	3	1¼	Whittaker.
Do.[c]	650	7	3	Whittaker, 3½ miles northwest.
Do	700	¼	1	Whittaker, 4½ miles northwest.
Do	550	¾	2	Whittaker.
Fountain Bros	1,250	20	2	Whittaker, 1½ miles northwest.
Do	900	¼	1	Do.
Do	900	¾	1¼	Do.
Do	900	1	1¼	Myers, 1 mile southeast.
A. L. Ewing	740	2	2	Myers, 1 mile south.
J. B. Rosprim	910	5	2	Myers.
G. G. Foster	900	20	2	Myers, 400 yards west.
Do	900	25	1¼	Myers, 800 yards west.
Adline Jones	850	20	2	Myers, 2 miles southwest.
Jas. Butler	840	25	2	Myers, 3 miles northwest.
Do	900	25	2	Myers, 3 miles north.
Do	850	20	2	Grant, ½ mile south.
Mit. Parker	630	12	1	Cooks Point, 3 miles east.
Do	585	12	1	Do.
Do	535	15	1	Pittbridge.
Do	630	15	1	Pittbridge, 1 mile west.
Do	835	35	1	Pittbridge, 4 miles south.
Do.[d]	750	30	2	Tunis, 1½ miles east.
Do	760	15	2	Tunis, 3 miles southeast.
T. M. Ewing[e]	511	2	2	Pittbridge, 1½ miles east.
Robt. Dennis	400	7	1	Pittbridge, 1½ miles northeast.
R. A. Rogers	420	2½	1	Stone City, 300 yards south.
Frank Aldridge[f]	760	2	1	Rita, 7½ miles south.
Joe Collier	800	5	1	Rita, 2 miles east.
T. F. Hudson	260	160	6	Caldwell, ½ mile northeast.
V. Leshikar	180	Small.	8	Caldwell, 5 miles southwest.
J. D. Rogers[g]	703	45	3	Somerville, 7 miles southeast.

[a] Temperature of water 77° F.; gas escapes from pipe.
[b] Continuous flow of gas; water salty.
[c] Gas associated with water.
[d] At 350 feet a flow of salt water associated with gas was obtained.
[e] Well flowed 60 gallons a minute at first, but is now becoming choked with sand.
[f] Oil well.
[g] Good flow obtained at 400 feet.

Analysis of water from deep well owned by Mit. Parker, 3 miles southeast of Tunis, Burleson County.[a]

	Parts per million.		Parts per million.
Potassium (K)	7	Sulphate radicle (SO_4)	630
Sodium (Na)	520	Carbonate radicle (CO_3)	520
Magnesium (Mg)	4		
Calcium (Ca)	11		1,756
Chlorine (Cl)	64		

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

Record of well at Clay, Burleson County.

	Feet.
.....	0– 15
.....	15– 28
.....	28– 41
.....	41– 67
te.....	67– 74
granite.....	74– 88
sand.....	88–124
sand rock.....	124–161
te.....	161–169
limestone rock.....	169–185
.....	185–188
sand rock.....	188–197
tone.....	197–217
.....	217–220
tone.....	220–249
blue sand.....	249–254
limestone.....	254–261
tone.....	261–271
.....	271–282
tone.....	282–420
water sand.....	420–480
tone.....	480–525
blue sand with lignite and soapstone.....	525–608
r sand.....	608–613
te and soapstone.....	613–632
r sand.....	632–636
tone and sand.....	636–647
r sand.....	647–687
.....	687–688

Analysis of water from deep well at Clay, Burleson County. [a]

	Parts per million.		Parts per million.
Na).....	490.0	Carbonate radicle (CO_3).....	30.0
n (Mg).....	8.0	Silica (SiO_2).....	38.0
Ca).....	21.0	Organic matter.....	79.0
Cl).....	490.0		
radicle (SO_4).....	4.6		1,480.6
ate radicle (HCO_3).....	320.0		

BRAZOS COUNTY.

ow wells.—Water in sufficient quantity to supply an ordinary ound in Brazos County from 35 to 60 feet below the surface. *ian wells.*—The best developed artesian area in Brazos County ed near Steeles Store and Stone City, between Little and Big rivers, where about 50 flowing wells are located. About 15 uthwest of Bryan there are a number of smaller artesian wells, in depth from 200 to 1,000 feet, but averaging about 300 th diameters of 1 to 3 inches. The smaller wells yield about

[a] ed by analyst in grains per gallon and hypothetical combinations; recomputed to parts and ionic form at U. S. Geol. Survey.

47 gallons a minute; the larger and deeper ones furnish considerabl more. In sinking the deep wells in this district several small flow are encountered before the main water horizon is reached. These a generally cased off and only the water from the lowest horizon allowe to flow. In addition to the above-described wells there are a few i the southern part of the county. A partial list of the artesian an deep wells of Brazos County is given below, also a record of th materials penetrated in the Hearne and Brazos Valley Railroad wel at Stone City.

Partial list of artesian and deep wells in Brazos County.

Owner.	Depth.	Flow.	Location.
	Feet.		
Hearne and Brazos Valley R. R.	1,005	.....	Stone City.
Templeton & Foster	.....	Flows...	Navasota, 6 miles west.
John D. Rogers	900	Flows...	Allenfarm.
Do	1,300	Flows...	Allenfarm, 1 mile west.

Record of Hearne and Brazos Valley Railroad well at Stone City, Brazos County.

	Feet.	
Surface blue clay	0–	25
Rock	25–	28
Blue clay	28–	60
Rock	60–	61
Blue marl	61–	105
Lignite	105–	106
Blue marl	106–	145
Rock	145–	147
Blue marl with an occasional layer of rock	147–	1,005

MADISON COUNTY.

Shallow wells.—Throughout Madison County good water is obtain from wells at depths of 50 to 80 feet, depending on the elevation the surface.

Artesian wells.—Owing to the ease with which good shallow wel are obtained and the numerous small flowing streams traversing t county, there is little need for flowing wells, and so far as can l ascertained no attempts have been made to develop this resource.

LEON COUNTY.

Shallow wells.—In Leon County shallow wells vary in depth fro 30 to 45 feet, and a good supply of water is generally struck.

Artesian wells.—The only artesian well in Leon County is th owned by J. H. Oliver. It is located one-half mile northwest Buffalo and has a depth of 1,200 feet.

FREESTONE COUNTY.

Shallow wells.—The shallow wells of Freestone County are from 35 to 45 feet deep and generally contain from 6 to 20 feet of water.

Artesian wells.—Owing mainly to the abundant supply of shallow-well water throughout the county, no attempts have been made to get artesian flows.

HOUSTON COUNTY.

Shallow wells.—Most of the shallow wells throughout Houston County are less than 40 feet deep, and a large supply of water is generally obtained.

Artesian wells.—At Crockett a well was sunk by Prof. J. B. Smith to a depth of 700 feet, and the water rose within 40 feet of the surface. There are several wells at Kenard 1,100 to 1,200 feet deep, from which a large supply of water is obtained by pumping.

ANDERSON COUNTY.

Shallow wells.—A good water supply is found in Anderson County at a depth of 30 to 40 feet below the surface.

Artesian wells.—There are no artesian wells in this county, but several deep borings have been made at Palestine and other places which furnish a good supply of water by pumping.

LIMESTONE COUNTY.

Shallow wells.—Water is secured in the southern part of Limestone County at a depth of about 35 feet. In the northwestern part the wells are somewhat deeper, averaging 60 feet.

Artesian wells.—There are no artesian wells in Limestone County, although it is believed that flows might be obtained if wells were sunk to a sufficient depth.

CHEROKEE, TRINITY, ANGELINA, SAN AUGUSTINE, AND SABINE COUNTIES.

Shallow wells.—Throughout Cherokee, Trinity, Angelina, San Augustine, and Sabine counties shallow wells find water at depths varying from 30 to 50 feet, and the supply is generally large.

Artesian wells.—The only artesian well in these counties is at Groveton, the county seat of Trinity County, where a 6-inch well 495 feet deep yields 27 gallons a minute. There is a deep well at Bronson, Sabine County, a record of which is given below, also an analysis of the water.

Record of deep well at Bronson, Sabine County.

	Fe
Yellow clay	0–
Blue clay	30–
Brown shale	60–
Sand	103–
Brown shale	115–
Sand	145–
Blue clay	155–
Limestone rock	163–
Blue clay	164–
Sand	258–
Blue clay	272–
Brown shale	322–
Blue clay	352–
Blue clay and "shell"	374–
Blue clay	380–
Sand rock	486–
Blue clay	489–
Blue clay and bowlders	578–
Blue clay	586–
Water sand	674–
Blue clay	729–
Dark sand	810–
Blue clay	818–
Blue shale and "shell"	892–
Dark shale	928–1,
Water sand	1,018–1,
Dark clay	1,068–1,

Analysis of water from deep well at Bronson, Sabine County.[a]

	Parts per million.		Parts pe
Sodium (Na)	330.0	Silica (SiO_2)	
Chlorine (Cl)	30.0	Organic matter	
Sulphate radicle (SO_4)	8 1		
Carbonate radicle (CO_3)	395		

NACOGDOCHES COUNTY.

Shallow wells.—Wells of moderate yield are obtained in N doches County at a depth of 25 feet.

Artesian wells.—Two wells have been sunk in this county an concerning them are given below.

Artesian wells in Nacogdoches County.

Owner.	Depth.	Flow per minute.	Diameter.	Distance from Nacog
	Feet.	*Gallons.*	*Inches.*	
Nacogdoches Ice Co	285	.....	4	¼ mile southwest.
Haywood Lumber Co	820	40	6	1 mile southeast.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to million and ionic form at U. S. Geol. Survey.

SHELBY, PANOLA, AND RUSK COUNTIES.

Shallow wells.—Water in Shelby, Panola, and Rusk counties is ained in abundance in wells ranging from 20 to 35 feet in depth.

Artesian wells.—There is little demand for artesian water in these nties, owing mainly to the shallow depth at which ground water y be obtained. At Center, Shelby County, there is a deep well, a ord of which is given below; also an analysis of the water.

Record log of deep well at Center, Shelby County.

	Feet.
Yellow clay	0– 10
Brown shale	10–106
Lignite	106–108
Brown shale	108–240
Sand	240–250
Brown shale	250–320
White sandstone	320–330
Brown shale	330–356
Lignite	356–358
Brown shale	358–372
White sandstone	372–374
Brown shale	374–416
"Stone coal"	416–417
Brown shale	417–443
Sandstone	443–445
Brown shale	445–517
"Gray granite"	517–520
Brown shale	520–556
Sandstone	556–557
Brown shale	557–562
"Gray granite"	562–564
White sand, water bearing	564–614
Brown shale	614–623

Analysis of water from deep well at Center, Shelby County.[a]

	Parts per million.		Parts per million.
ium (Na)	370.0	Silica (SiO_2)	24.0
ium (Ca)	4.1	Organic matter	31.0
orine (Cl)	57.0		930.1
phate radicle (SO_4)	14.0		
bonate radicle (CO_3)	430.0		

VAN ZANDT AND RAINS COUNTIES.

Shallow wells.—Throughout Van Zandt and Rains counties an adeate supply of water is obtained from wells ranging in depth from 20 45 feet.

Artesian wells.—There are at present no flowing wells in either of se counties; and, so far as can be ascertained, no prospecting for esian water has been done.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per on and ionic form at U. S. Geol. Survey.

SMITH COUNTY.

Shallow wells.—In Smith County water occurs at shallow depths, rarely exceeding 35 feet, and the supply is usually large.

Artesian wells.—A few years ago an oil well was drilled on the county poor farm to a depth of 460 feet and a strong flow of water obtained. No other deep borings have been reported from this county, but it is believed that artesian water could be obtained at other localities if wells were sunk to a sufficient depth.

WOOD AND GREGG COUNTIES.

Shallow wells.—Water is found in Wood and Gregg counties at depths ranging from 25 to 80 feet. The supply is large and the quality generally good, but a few wells near Quitman and Winnsboro furnish water containing a large percentage of mineral salts.

Artesian wells.—No flowing wells have been reported from either of these counties. About 6 miles south of Longview, Gregg County, an oil well was sunk to a depth of 1,424 feet without obtaining artesian water. It is possible that flows might be found at shallower depths in Wood County or in other parts of Gregg County, but thus far no tests have been made in these localities. A record of the deep oil well near Longview is given below:

Partial record of well 6 miles south of Longview, Gregg County.

	Feet.
No record	0– 285
Soapstone	285– 305
Flint	305– 307
Soapstone	307– 322
Shaly clay	322– 329
Sandy shale	329– 353
Clay	353– 356
Sandy shale	356– 437
Clay	437– 452
Sandy shale	452– 487
Flint	487– 489
Sandstone	489– 543
Lignite	543– 545
Clay	545– 551
Sand	551– 571
Flint	571– 574
Sandy shale	574– 710
Clay	710– 745
Sandstone	745– 756
Water-bearing sand	756– 780
Sandstone	780– 880
Clay	880– 892
Sandy shale	892–1,027
Clay	1,027–1,034
Sandy shale	1,034–1,199
Flint	1,199–1,200
Sandstone	1,200–1,246
Sandy shale	1,246–1,424
Gumbo.	

UPSHUR COUNTY.

Shallow wells.—In Upshur County the water table appears to be about 35 to 40 feet below the surface, and at this depth a good supply of relatively pure water is obtained.

Artesian wells.—The only artesian well which has been reported from this county is on the John Gillis ranch, 1½ miles southwest of Hawkins. It is 250 feet deep and yields a flow of 2½ gallons a minute.

HARRISON COUNTY.

Shallow wells.—In Harrison County sufficient water for ordinary domestic purposes is struck at depths rarely exceeding 40 feet, and the quality is usually good.

Artesian wells.—The only artesian well in Harrison County is owned by the Marshall waterworks. This well was bored in January, 1900, and the first flows were obtained at shallow depths. It is 208 feet deep, 6 inches in diameter, and has a flow of 200,000 gallons every twenty-four hours. The following is a record of the material penetrated:

Record of artesian well at Marshall, Harrison County.

	Feet.
Soil and clay	0– 80
Sand with rock at base, water bearing	80–100
Clay with layers of lignite	100–160
Sand with rock at base, water bearing	160–180
Sand, water bearing	180–208

This test well was made without a strainer, and considerable sand was brought up with the water. The test was continued for about twelve hours with no apparent change of flow.

MARION COUNTY.

Shallow wells.—Water in Marion County is found at 25 to 50 feet below the surface, and the supply is both abundant and pure.

Artesian wells.—The only artesian well reported from this county is owned by J. M. De Ware, at Jefferson. It is 2 inches in diameter, 801 feet deep, and yields a small flow, but the exact amount has not been ascertained.

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WS 183. Flowing wells and municipal water supplies in the middle and northern portions of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 393 pp., 5 pls.

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The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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THE

GEOLOGY AND WATER RESOURCES

OF THE

ESTERN PORTION OF THE PANHANDLE OF TEXAS

BY

CHARLES N. GOULD

WASHINGTON

GOVERNMENT PRINTING OFFICE

1907

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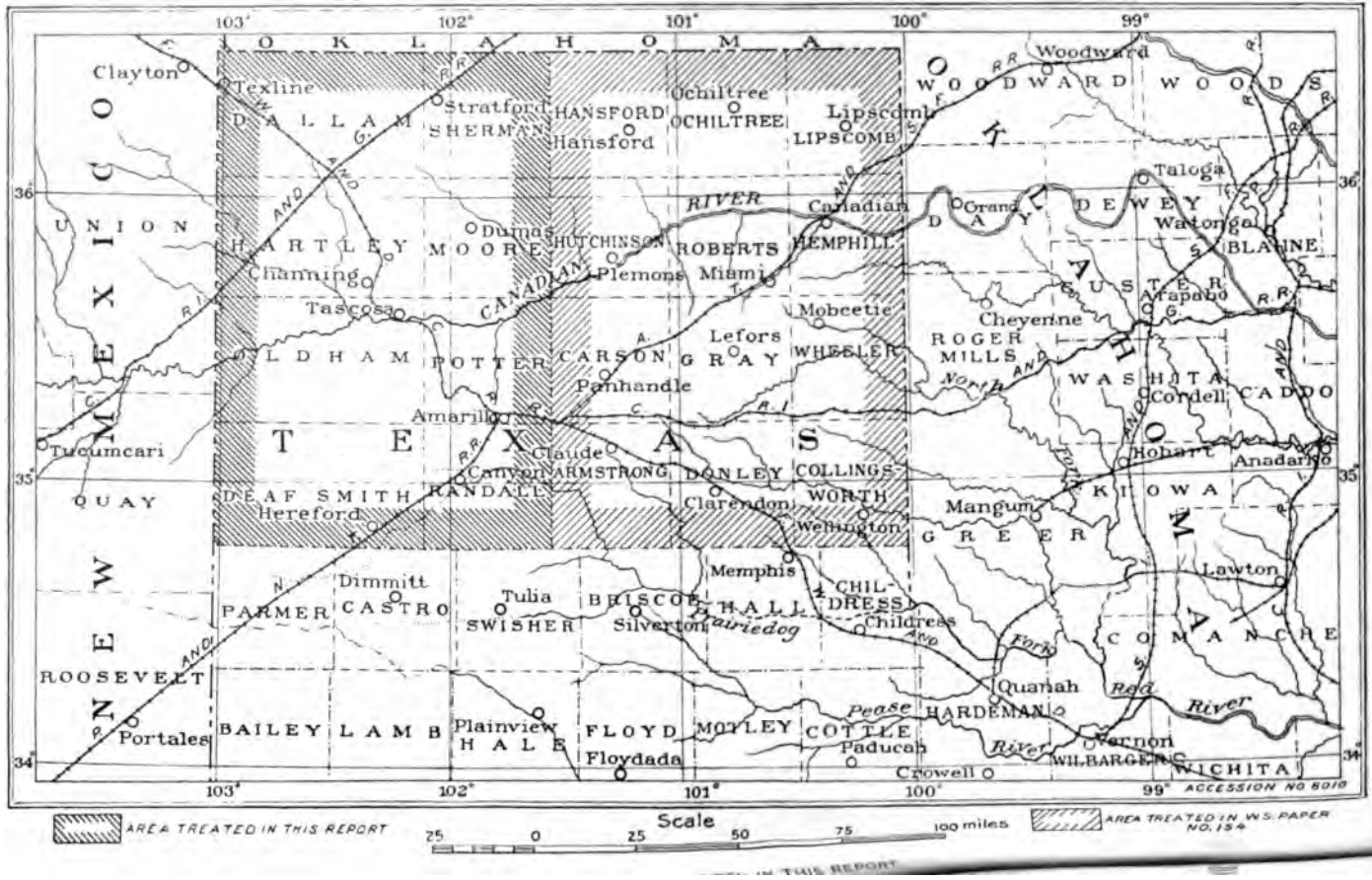
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NEW MEXICO
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Ochiltree
OCHILTREE
Lipscomb
LIPSCOMB
Woodward
WOODWARD
WOODS
Taloga
DEWEY
Watonga
BLAINE
Canadian
RIVER
Dumas
HUTCHINSON
ROBERTS
HEMPHILL
Grand
DAY
CUSTER
Arapaho
Cheyenne
ROGER MILLS
WASHITA
Cordell
CADDO
UNION
HARTLEY
MOORE
Channing
Tascosa
Plemons
Miami
Mobeetie
Lefors
OLDHAM
POTTER
CARSON
GRAY
WHEELER
Panhandle
Amarillo
Tucumcari
Claude
Canyon
ARMSTRONG
DONLEY
COLLINGSWORTH
Clarendon
Wellington
Hobart
Anadarko
KIOWA
Mangum
GREER
QUAY
DEAF SMITH
Hereford
RANDALL
Memphis
Lawton
Dimmitt
PARMER
CASTRO
Tulia
SWISHER
BRISCOE
HALL
CHILDRESS
Childress
Silverton
Quanah
COMANCHE
ROOSEVELT
Portales
BAILEY
LAMB
Plainview
HALE
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MOTLEY
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Prairiedog Fork
North Fork
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AREA TREATED IN W.S. PAPER NO. 154
ACCESSION NO 8010

GEOLOGY AND WATER RESOURCES OF THE WESTERN PORTION OF THE PANHANDLE OF TEXAS.

By CHARLES NEWTON GOULD.

INTRODUCTION.

Area covered.—The area described in this report lies in the western part of the Panhandle of Texas and includes Sherman, Moore, Potter, Randall, Dallam, Hartley, Oldham, and Deaf Smith counties. The region is 120 miles long and 78 miles wide and contains approximately 9,360 square miles. It extends from 101° 35′ to 103° west longitude and from 34° 45′ to 36° 30′ north latitude, and is bounded on the north by Oklahoma and on the west by New Mexico. Its location is shown in Pl. I.

Sources of data.—During the summer of 1903 the writer, accompanied by several students from the University of Oklahoma, made a reconnaissance across the Panhandle of Texas, noting the general geologic and hydrographic features of the region. The greater part of the field work which forms the basis of this report was done, however, during the field season of 1905, with the assistance of Messrs. T. B. Matthews and E. F. Schramm. A detailed study was made of each of the above-mentioned counties, special attention being given to the valley of Canadian River and to Palo Duro Canyon. The work was done under the direction of Mr. N. H. Darton.

The well records, from which much of the information regarding the underground-water conditions was derived, were obtained partly in the field and partly by correspondence.

This report is a continuation of Water-Supply and Irrigation Paper No. 154, United States Geological Survey, which relates to the eastern part of the Panhandle.

TOPOGRAPHY.

GENERAL FEATURES.

The region described in this report is situated in the southern part of the Great Plains. It has a slope to the east of approximately 10 to 12 feet to the mile and a slight gradient to the south. The highest portion is in the extreme northwestern part of the State, where an

elevation of nearly 4,800 feet is attained. The lowest points are in Palo Duro Canyon in eastern Randall County and in the valley of Canadian River in southern Moore County, both of which are approximately 2,800 feet above sea level. The greater part of the area lies at an altitude between 3,500 and 4,500 feet.

The topography of the region is essentially of two types—the High Plains province, which is nearly level, and the canyon district, the surface of which has been deeply eroded.

HIGH PLAINS.

With the exception of Canadian River and Palo Duro Canyon the region here discussed is typical of the High Plains province. To the portion of the plains south of Canadian River the term Llano Estacado, or "Staked Plains," is applied. It is bounded for the most part by a steep escarpment 100 to 400 feet high, separating it from the lower eroded plains which surround it on all sides. In the western part of the Panhandle, however, this steep escarpment is in many places much reduced or entirely absent, and the descent from the High Plains to the river valley is gradual. That portion of the High Plains lying north of Canadian River has no distinctive name. It does not differ materially, however, from the Llano Estacado, except that it is in but few places bounded by steep escarpments, but slopes gradually to the river valleys and the lower eroded plains to the east.

The deposits comprising the Great Plains are probably of river origin. According to the generally accepted theory, this area was formerly occupied by a network of meandering rivers which had their sources in the Rocky Mountains. These streams, being overloaded, were constantly depositing sediment, which filled the stream beds and forced the rivers into new channels. By this continued shifting irregular layers of sand were deposited upon the red beds, which constitute the basal formation of this region. This process was continued until a deposit several hundred feet thick was laid down over much of the region east of the Rocky Mountains.

The present streams are now eroding this level plain, but their work is generally not far advanced. In a few instances, however, they have cut their valleys through the superficial deposits into the underlying red beds, a feature well illustrated by Palo Duro Canyon and Canadian River. Along the edges of the High Plains small streams are cutting their way headward, but their progress is slow, owing to the meager precipitation of the region incident to the general aridity of the climate.

The surface of the High Plains is generally flat, with nothing to break the severe monotony. The drainage is for the most part wholly undeveloped. There is no run-off, and the rainfall either evaporates directly, sinks into the soil, or collects in buffalo wallows and broad,

shallow depressions locally known as "playa lakes," from which it can escape only by seepage or evaporation. Here and there on this flat upland is a draw or incipient stream channel, in which after a heavy rain the water collects and runs off. If traced for any considerable distance these immature drainage ways will usually be found to end in a playa lake. Not uncommonly several of these lakes are connected by a shallow stream channel which wanders over the prairie, with a gradient so slight in many places that it is impossible to ascertain the downstream direction. In a number of cases, however, the shallow draws form the beginning of a creek which flows across the escarpment and eventually becomes a stream of some magnitude. On the High Plains north of Canadian River, Coldwater, Carriso, Perico, Big Blue, and Palo Duro creeks are all streams of this type, having their origin in conspicuous draws on the level plains. South of Canadian River Tierra Blanca and Palo Duro[a] creeks are also of this character.

Except for portions of Hartley, Moore, Oldham, Potter, and Randall counties, in which stream erosion has cut relatively deep valleys and canyons in the level surface, practically the entire region included in this report consists of high plains.

The area shown as Tertiary on the geologic map (Pl. III) comprises the greater part of the High Plains area.

VALLEYS AND CANYONS.

CANADIAN RIVER VALLEY.

The Panhandle of Texas is traversed through its central portion by the valley of Canadian River, which enters the State from New Mexico after draining a considerable area in the northeastern part of that Territory. It flows a little north of east across the Panhandle, entering Oklahoma near the middle of the east line of Hemphill County. It leaves the area described in this report near the southeast corner of Moore County. The distance traveled by the river within this area is 85 miles, in which it descends from an altitude of 3,400 to 2,800 feet, a gradient of about 7 feet per mile.

Throughout its course across the Panhandle the Canadian Valley has been excavated in the level plain which formerly extended uninterruptedly across the entire western Texas region. The depth of the valley averages about 600 feet, and its width varies from 20 to 35 miles. The slopes are deeply dissected by numerous tributaries, presenting many irregularities. The stream bed is in most places sand

[a] There are in the Panhandle of Texas two creeks named Palo Duro. One, in the northern part of the area, rises near the Sherman-Moore county line and flows northeastward, emptying into Beaver Creek, a tributary of North Canadian River. The other creek of the same name, which is in the southern part of the Panhandle, flows eastward into South Fork of Red River. It is the latter stream that has carved out the deep canyon described on p. 11.

choked and varies in width from 200 to 600 yards, while the flood plain ranges from a few rods to 3 miles.

The topography immediately adjacent to the stream is of two general types, depending on the character of the rocks. The valley has been cut through the upper Tertiary deposits into the red beds. The Tertiary formations consist generally of soft sands and clays, homogeneous in character, while the red beds are composed of alternating strata of hard and soft rocks. One member of the red beds, a hard, massive dolomite, resists erosion in a marked degree. This ledge of dolomite is in places exposed on the tops of bluffs 200 feet above the river, while in other places it is carried beneath the stream bed by a series of folds. Wherever exposed the dolomite caps conspicuous bluffs bordering the river for miles, and between these bluffs the stream flows in a narrow channel with an inconspicuous flood plain. Where this dolomite ledge is absent the flood plain may reach a width of 2 to 3 miles and is in many places covered with sand hills.

Numerous tributaries, few of which exceed 20 miles in length, enter Canadian River on each side. Each of these streams has carved a valley of greater or less width and depth in the sides of the main valley, the average gradient of these minor valleys being about 35 feet per mile. In the localities where dolomite is present these tributary streams have carved narrow canyons through this and the underlying formations, as in the case of Trujillo, Las Achias, Tecovas, West Amarillo, Big Canyon, Plum, Alibates, and Big Blue creeks. Where the dolomite is absent the side slopes of the minor valleys are more gentle.

PALO DURO CANYON.

Palo Duro Canyon is located in eastern Randall County, near the southeast corner of the region under discussion. Palo Duro Creek has its source in eastern New Mexico, near the western part of the Llano Estacado, as a dry, shallow draw, and continues thus eastward for 40 miles. In the western part of Randall County it has cut a valley averaging 50 feet in depth and a quarter of a mile in width. From this locality springs appear in increasing numbers as far as Canyon, where Palo Duro is joined by Tierra Blanca Creek. The junction of these two creeks, each of which carries approximately 15 second-feet of water, forms a stream of sufficient size to cause considerable erosion, particularly in soft rocks, such as the Tertiary and red-beds formations, and from Canyon eastward the valley deepens rapidly. In its upper course it is typically V-shaped and so continues for a number of miles until in its downward cutting the stream encounters a ledge of relatively hard sandstone in the upper part of the red beds, when corrosion is checked and the valley widens, becoming U-shaped. At the falls, 15 miles northeast of Canyon, the stream

A. TRIASSIC SANDSTONE ABOVE RED CLAY, SHOWING CHARACTERISTIC EROSION.

B. FALLS IN PALO DURO CANYON CAUSED BY HARD LEDGE OF TRIASSIC SANDSTONE.

cuts through the sandstone, as shown in Pl. II, *B*, and from that point to the eastern side of Randall County it flows through a deep, narrow, V-shaped valley in relatively soft red beds.

In the eastern part of Randall County, Palo Duro Canyon is a picturesque gorge, 700 to 800 feet deep, eroded in the flat surface of the plains. From the rim of the canyon the slope is everywhere abrupt and in many places precipitous for a distance of several hundred feet. At the point where the canyon passes from Randall County the width of the valley at the bottom averages about a quarter of a mile, while the distance from rim rock to rim rock is not more than 1½ miles. Tributary to Palo Duro Canyon are a number of small creeks, the largest being Canyon Cita, Sunday, and Timber creeks, all of which have cut short but deep canyons into the High Plains. The sides of the main canyon, like those of the smaller streams, are cut into innumerable deep V-shaped gullies with sharp intervening ridges. The action of erosion on rocks composed of alternating layers of hard and soft strata has produced an infinite number of the conspicuous and in many cases unique forms characteristic of badlands topography. Some of these forms are shown in Pl. II, *A*. The alternation of varicolored shales, brown sandstone, and green vegetation, mingled with the unique erosional forms, gives to the canyon a degree of picturesqueness not often found on the plains.

MINOR STREAM VALLEYS.

With the exception of the Canadian River valley and Palo Duro Canyon there are no large valleys in the region. In certain places, however, the monotonous level of the High Plains is interrupted by shallow valleys, which extend across it, as a rule, in an easterly direction. These valleys are for the most part nothing but dry, meandering channels a few feet deep, which have been eroded in the level upland. They are known locally as "draws" or "arroyos." Brief descriptions are here given of the more important, in order, from north to south.

Beaver Creek valley.—Beaver Creek, which flows eastward across Beaver County, Okla., for nearly its entire course, bends to the south near the Dallam-Sherman county line and flows for 15 miles or more across the northern part of Sherman County. It is here a dry stream with a sandy bottom in a valley averaging 50 feet in depth and a quarter of a mile in width.

Coldwater Creek valley.—Coldwater Creek is one of the southern tributaries of Beaver Creek, in Beaver County, Okla. In its upper course the stream is sometimes called Rabbit Ear Creek, from the fact that it rises near the Rabbit Ear Mountains, two volcanic peaks in northeastern New Mexico. It flows southeastward across Dallam and Sherman counties in a valley averaging a quarter of a mile

in width and 50 feet in depth, becoming wider and deeper to the east. Except in the vicinity of Buffalo and Agua Fria springs, in Dallam County, Coldwater Creek carries only flood water.

Palo Duro Creek valley.—This stream (which must not be confused with Palo Duro Creek, farther south) is also a tributary of Beaver Creek. It rises on the High Plains north of Canadian River and flows for a short distance through southern Sherman and northern Moore counties. The channel is shallow, not averaging more than 25 feet in depth, and is dry for the greater part of the year.

Carriso and Perico Creek valleys.—These are shallow channels, each of which enters Texas from New Mexico and follows a tortuous course among sand dunes southeastward across the western part of Dallam County. The two streams unite just west of Dalhart, forming Rita Blanca Creek, which flows southward entirely across Hartley County and into Oldham County before joining Canadian River. Normally both Carriso and Perico creeks are dry sand beds, 20 to 50 feet deep and 100 to 500 yards wide.

Big Blue Creek valley.—Big Blue Creek rises in Moore County and flows southeastward into the Canadian. In its upper course it is merely a dry sand bed, but it gradually deepens its valley until in the southeastern part of the county it flows in a canyon 400 feet deep which it has cut through the superficial Tertiary deposits and into the red beds. In its middle and lower portions it carries a considerable amount of water, derived from springs in Tertiary and red-beds rocks.

Tierra Blanca Creek valley.—Tierra Blanca Creek rises on the Llano Estacado south of Canadian River in eastern New Mexico, flows eastward across Deaf Smith County, Tex., and unites with Palo Duro Creek at Canyon. In its upper course it is only a "draw" in the flat prairie. Near Hereford, the county seat of Deaf Smith County, springs begin to appear, and from that point to Canyon the valley averages 75 feet in depth and half a mile in width. Along the sides of the valley are white cliffs of Tertiary clay.

GEOLOGY.

GENERAL STATEMENTS.

The rocks of the region are all of sedimentary origin and belong to the following geologic systems: Carboniferous (Permian), Triassic, Cretaceous, Tertiary, and Quaternary. The areal distribution of these formations is shown by the geologic map (Pl. III) and their structural relations by cross sections (Pl. IV). All the rocks lie comparatively level or have slight but regular dips to the east.

he order and age of the formations are shown in the following e:

Geologic formations of the Texas Panhandle.

System.	Formation.	Characteristics.
·rnary	Alluvium	Sand, clay, and loam.
	Sand dunes	Wind-blown sand.
	Equus beds	Sand and clay.
ary	Undifferentiated	Sand, clay, and gravel, loosely consolidated.
ceous	Dakota (?)	Brown to yellow soft sandstone and clay.
	Dockum group. Trujillo	Red shales.
		Red to gray sandstone and conglomerate (upper sandstone).
		Red shales.
		Red to gray cross-bedded sandstone and conglomerate (middle sandstone).
sic		Red shales.
		Massive to cross-bedded sandstone (lower sandstone).
	Tecovas	Dark-red or magenta shales and soft sandstones.
		Variegated shales and soft sandstones.
	Quartermaster	Red clay.
		Massive white dolomite (Alibates lentil).
		Red clays.
oniferous (Permian)		Massive white gypsum (Saddlehorse lentil).
	Greer	Red shales.
		Massive white gypsum in ledges interstratified with red shales.

by far the greater part of these rocks are of Permian, Triassic, or tiary age. The Permian and Triassic rocks are generally spoken as red beds, owing to the predominating color of the clay which ns a large proportion of these deposits.

'arther east in Texas and particularly in Oklahoma the Permian beds are well exposed and have been divided into five formations,[a] Enid, Blaine, Woodward, Greer, and Quartermaster. In the on here described only the two upper formations of the Permian beds occur, and these are found in the deep canyons, where erosion cut through the overlying Triassic and Tertiary formations. The assic red beds are exposed along the edge of the Llano Estacado in as and New Mexico, as well as in the canyons cut by the various ams that rise in the southern part of the High Plains. Cretaceous cs are found in but a few small areas in the extreme northwestern of the region. Tertiary deposits, which make up the greater of the rocks of the High Plains, are exposed along the escarpits at the edge of the plains, in the shallow valleys, and near the s of the deep canyons which traverse them. Quaternary rocks, sisting mainly of dune sand and alluvium, form the superficial osits in parts of the region and are now being shaped by wind, er, and other agents of erosion.

[a] For a discussion of the correlation of the Kansas, Oklahoma, and Texas Permian see Water-Sup. Paper No. 148, U. S. Geol. Survey, 1905, pp. 34-39; and No. 154, 1906, pp. 15-23.

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.....	Undifferentiated		Sand, clay, and gravel, loosely consolidated.
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	Dockum group.	Trujillo	Red shales.
			Red to gray sandstone and conglomerate (upper sandstone).
			Red shales.
			Red to gray cross-bedded sandstone and conglomerate (middle sandstone).
			Red shales.
.....			Massive to cross-bedded sandstone (lower sandstone).
		Tecovas	Dark-red or magenta shales and soft sandstones.
			Variegated shales and soft sandstones.
		Quartermaster	Red clay.
			Massive white dolomite (Alibates lentil).
			Red clays.
is (Permian)....			Massive white gypsum (Saddlehorse lentil).
			Red shales.
		Greer	Massive white gypsum in ledges interstratified with red shales.

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PERMIAN.

GREER FORMATION.

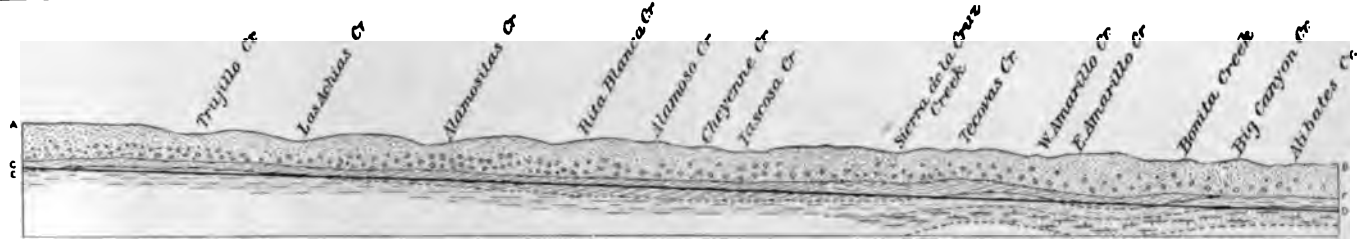
The Greer formation, as exposed in the western part of the Panhandle of Texas, consists of red-clay shale interstratified with one or more ledges of hard massive gypsum, which is white, as a rule, but here and there exhibits pinkish or bluish tints. The greatest thickness of the gypsum observed in the district is 20 feet. It is exposed in the lower portion of Canadian and Palo Duro valleys.

Along Palo Duro Canyon, in the extreme eastern part of Randall County, the Greer gypsum is exposed in the bottom and along the sides of a few small gullies which empty into Canyon Cita Creek half a mile above its junction with Palo Duro Creek. A short distance east of the Randall-Armstrong county line, however, the gypsum becomes more conspicuous along the bottom of the canyon and forms heavy ledges, one of which, 3 miles from the county line, is shown in Pl. V, *B*. About 12 miles farther east the gypsum outcrops as a persistent ledge 20 to 50 feet thick 100 feet or more above the bed of the river, forming the cap of an intercanyon escarpment which extends for more than 50 miles along the stream.

In the valley of Canadian River, in northeastern Potter and southeastern Moore counties, the gypsum beds of the Greer formation outcrop on both sides of the river, as well as along several tributary streams, particularly in the lower valleys of Alibates, Turkey, Plum, Saddlehorse, and Big Canyon creeks. It is most commonly seen capping rounded mounds or small flat-topped buttes standing out in the level valley or as extensive flat areas of soft gray or white gypsite or earth gypsum. The gypsum also occurs locally in this region as a heavy white, pinkish, or bluish ledge 10 to 15 feet thick, exposed along the small ravines which empty into the larger creeks or on the slopes of some of the higher hills. The thickness of the ledges is not constant, for here, as elsewhere, the lenticular nature of the various members of the red beds is well illustrated. If traced for a few hundred yards a 15-foot ledge of gypsum which outcrops along the side of a hill may be found to thin out noticeably or even to disappear entirely, its place being taken by sandstone or shale.

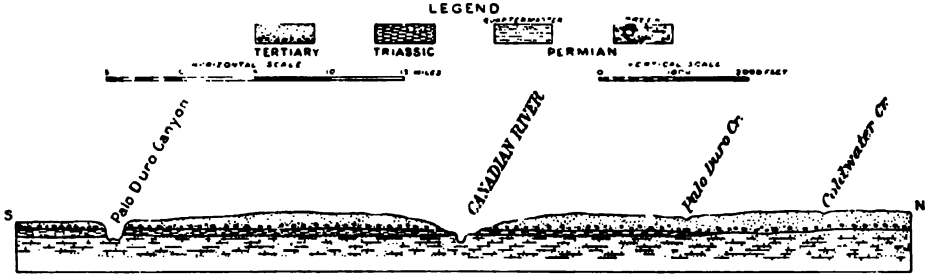
The beds are in many places tilted at various angles, which gives them the appearance of having been folded or thrown into a series of waves. This phenomenon, which is much more pronounced farther east than it is in this region, has usually been explained on the hypothesis of subterranean erosion of the soft shales and gypsum rather than that of regular folding.[a] As is shown later, however (see pp. 18–21), there is in the red beds of this part of the Panhandle

[a] See Water-Sup. and Irr. Paper No. 154, U. S. Geol. Survey, 1906, p. 20.



SECTION ALONG CANADIAN RIVER IN NORTHWESTERN TEXAS SHOWING STRUCTURE OF THE RED BEDS.

A Level of high plains
C Bed of Canadian River
EF Uniform dip (enlarged)



SECTION ALONG THE EAST LINE OF SHERMAN, MOORE, POTTER, AND RANDALL COUNTIES

ACCESSION NO 7913

GEOLOGIC SECTIONS ACROSS AREA TREATED IN THIS REPORT.

a well-marked series of anticlinal and synclinal folds, though it is not known that these had any influence on the relatively small and erratic folds and dips of the Greer formation.

QUARTERMASTER FORMATION.

General description.—The Quartermaster formation, which rests conformably upon the Greer, consists for the most part of soft red sandstones and red sandy clays and shales. In Oklahoma, where it is typically exposed, sandstone predominates to such a degree that the formation was originally designated the Quartermaster sandstone, but in the western part of the Panhandle red shales and clay make up the major portion of the beds, although soft red sandstones are by no means rare. In western Oklahoma and along the eastern escarpment of the Llano Estacado, in the eastern part of the Panhandle, the thickness of the Quartermaster formation varies from 200 to 300 feet, but farther west it is not so thick, averaging perhaps 150 feet, with a known maximum of 240 feet.

The red shales of the lower part of the Quartermaster formation, just above the top of the Greer gypsum, contain a considerable amount of gypsum, most of which is in the form of bands of white or pinkish satin spar. Locally these bands lie parallel to the bedding, but in many places they are arranged in an irregular crisscross manner throughout the shale. At higher horizons there are certain lentils, composed of massive gypsum and dolomite, which are restricted to definite localities. These are described later. (See pp. 16–18.)

The greater part of the Quartermaster formation in the western Panhandle region consists of alternating beds of brick-red, more or less sandy clay and scattered ledges of soft red clayey sandstone. So similar in appearance are the shales and sandstones, however, that it is frequently difficult in the field to separate one sharply from the other. Being soft, both the shales and sandstones are susceptible to weathering and where exposed form typical badlands topography. Owing to the homogeneity of the material of which they are composed, the erosion figures produced are usually more or less conical or pyramidal in form. Many of them are large, reaching 100 feet in height, as shown in Pl. V, A.

The Quartermaster formation has many local and erratic dips and folds, which give to the rocks a peculiar wavelike structure, very noticeable along the sides of cliffs in certain localities. As a rule the dipping does not seem to be caused by ordinary folding, but, as in the case of the rocks of the Greer formation, by subterranean erosion, which has carried away the soft shales and soluble gypsums beneath and permitted the upper members to sink to lower levels.

In Palo Duro Canyon, in eastern Randall County, the Quartermaster formation is well exposed both along the main canyon and on various tributary streams, particularly Canyon Cita, Sunday, and Timber creeks. With the exception of a few inconspicuous outcrops of the Greer gypsum it is the lowest formation exposed in the canyon and may be traced for 10 miles or more above the point where Palo Duro Creek leaves the county. Along the edge of the canyon the vivid brick-red shales which constitute the Quartermaster are easily distinguished from the somewhat less brilliant maroon, yellow, magenta, and light-colored shales of the Triassic red beds and Tertiary deposits higher in the canyon wall.

The Quartermaster formation is also well exposed in the valley of Canadian River, where it is characterized by two marked peculiarities not noticeable in Palo Duro Canyon. First, the Quartermaster formation and also the overlying Triassic rocks have been folded into broad, shallow anticlines and synclines (see Pl. IV, p. 14), which are recognized only when the structure is studied in a broad way;[a] and, second, the formation here contains two members (classed as lentils), one of gypsum and one of dolomite, which so far as known do not appear elsewhere in Texas or Oklahoma.

Saddlehorse gypsum lentil.—In the valley of Canadian River, at 60 to 80 feet above the base of the Quartermaster formation, there occurs a ledge or ledges of massive white gypsum interstratified with the red shales. In some places the gypsum is a single ledge 4 feet or more thick; in others there are two ledges respectively 2 and 3 feet thick, separated by red clay; and here and there even three separate ledges are observed. The total thickness of the gypsiferous beds, however, rarely exceeds 10 feet.

This gypsum, known as the Saddlehorse lentil, from one of the creeks on which it typically occurs, is exposed along the bluffs of various creeks tributary to the Canadian, particularly on Big Canyon, Plum, Alibates, Saddlehorse, and Turkey creeks in eastern Potter County, and on Dixon and Antelope creeks in Carson County. Farther west, on West Amarillo, Horse, and Tecovas creeks and along the bluffs of Canadian River, the gypsum appears in the lower part of the bluffs, as shown in Pl. VI, *B*. In the extreme western part of the State, near the mouth of Trujillo Creek and along the bluffs bordering the Canadian both above and below this point, the gypsum also occurs in two ledges, each 3 feet thick. The Saddlehorse lentil is not exposed between Las Achias and Tecovas creeks, a distance of 35 miles, but, as will be explained later, there is in this region a synclinal fold in the red beds which carries all the Permian rocks beneath the surface. The gypsum lentil is not known to occur in Palo Duro Canyon nor at points in western Oklahoma and in the eastern part of the Pan-

[a] See pp. 18-21 for a further discussion of this subject.

EROSION OF THE QUARTERMASTER FORMATION IN PALO DURO CANYON.

B TYPICAL VIEW OF GREEN GYPSUM IN PALO DURO CANYON.

idle of Texas, where the Quartermaster formation is typically osed.

Alibates dolomite lentil.—In the upper part of the Quartermaster mation, wherever it is exposed along Canadian River, there occurs ery persistent ledge of dolomite. It is white, massive, and more less flinty, and exhibits definite lines of lamination which have a vy, plicated structure. This dolomite, which is designated the bates lentil, from Alibates Creek, where it is well exposed, is the dest rock exposed in the region, and for that reason resists erosion l forms the cap rock of conspicuous bluffs and cliffs along Canadian er and many of its tributaries. The rock is cut by a regular series master joints and on weathering breaks into rectangular blocks ich lodge on the slopes below. Usually there are two distinct omite ledges, the lower being 8 feet and the upper 2 feet thick. ey are separated by 4 feet or more of red clay, so that the com- ed thickness of the dolomite and interbedded clay is approximately feet.

This dolomite is considered a lentil from the fact that so far as own it does not occur elsewhere in the Quartermaster formation. ere is a ledge of white dolomite in the Quartermaster on Salt Fork Red River 3 miles north of Clarendon, Tex., and another on South rk of Red River about 10 miles southwest of Clarendon, but neither these is known to occur at the same horizon as the Alibates.

In its general structure the Alibates dolomite resembles very closely Day Creek dolomite, which constitutes the upper member of the odward formation of the Permian red beds in Kansas and Okla- ma. Like the Day Creek it is white, hard, massive, and laminated, sisting usually of two ledges separated by red clay and forming cap of conspicuous bluffs and numerous small canyon walls in the ion where it outcrops.

n some places the appearance of the dolomite differs slightly from normal. A noteworthy example is near the mouth of Trujillo ek east of the New Mexico line, where it is a light-brown or yellow- gray rock. In structure it exhibits peculiar wavy laminations and racteristic block fracture, but as seen in the ledge or in fresh frac- it resembles a hard, fine-grained quartzite. Chemical analysis, ever, shows that calcium and magnesium carbonate are present h only a small percentage of silica. In the Trujillo locality the omite contains a larger amount of flint, occurring in the form of gated concretions, than is common in most places. Flint is also sent in considerable quantities in the upper ledge of the Alibates ng Big Canyon Creek in northern Potter County, where fragments w the ground along the divides between various branches of the k. Here and there in this vicinity the dolomite outcrops on the

surface, revealing the fact that the entire ledge has here become agatized. It exhibits a most beautiful combination of colors, chiefly red, blue, and white. Rejects and chipped flakes scattered on the surface indicate that the Indians have used the flint in the manufacture of arrow points and other implements.

The fact has been mentioned that an anticline-syncline structure is exhibited along the valley of Canadian River. As the Alibates dolomite is the hardest rock found anywhere along this valley it serves as a convenient horizon of reference, and by means of it the system of folds may be traced in most places with comparative accuracy. For this reason mainly the structure and exposures of the dolomite will be discussed at the same time. Along Canadian River the dip of most of the formations is about the same as the slope of the plains or of the stream bed, being approximately 10 feet to the mile toward the east. This is shown by the fact that the Alibates dolomite is found at nearly the same height above the river in eastern Moore and Hutchinson counties as it is near the New Mexico line 80 to 100 miles farther west. Pl. IV (p. 14) illustrates the structure of the beds.

The easternmost exposure observed of the Alibates dolomite lentil is on the bluffs north of Canadian River east of Plemons, the county seat of Hutchinson County. It forms the cap of conspicuous bluffs along the river and several of its tributaries, notably Kit Carson, Dixon, and Antelope creeks, in Hutchinson and Carson counties. In southeastern Moore and northeastern Potter counties it is on the bluffs along a number of creeks, the chief of which are Big Blue, Plum, Big Canyon, Saddlehorse, Turkey, and Alibates. In this region the height of the ledge above the river varies from 180 to 250 feet. In this region also the Greer gypsum is exposed along the Canadian and the various minor streams as mounds in the valleys or as ledges near the stream level. The vertical distance between the Greer gypsum and the Alibates dolomite varies locally from 180 to 200 feet, the maximum observed interval being on the Leaverton ranch, near the Moore-Potter county line. The following sections illustrate the structure of the Quartermaster formation in this region:

Section of Quartermaster and Greer formations on Big Canyon Creek, northern Potter County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Carboniferous. (Permian.)	Quartermaster	Alibates lentil.	Flinty dolomite capping bluffs	3
			Red shale	4
			Massive white dolomite	8
			Red shale with white bands and ledges of soft sandstone.	60
		Saddlehorse lentil.	White gypsum, locally exposed as one ledge 4 feet thick or as two ledges 2 and 3 feet thick separated by shale.	4–10
			Red shale and sandstone with selenite bands in the lower part.	80
	Greer		Massive gypsum, exposed in ledges, in many places capping low mounds in creek bottom.	15
			Red shales	40

Section of the Tertiary and of the Quartermaster and Greer formations on the bluffs north of Canadian River at Leaverton ranch, southeastern Moore County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Tertiary			Clays and sands exposed in cliffs	150
Unconformity.				
Carboniferous. (Permian.)	Quartermaster		Red shale on slope	60
		Alibates lentil.	White massive dolomite forming cap of bluff.	10
			Red shale	50
		Saddlehorse lentil.	White gypsum	4
			Red shale	8
			Blue shale	6
			Red shale and soft red sandstone with satin spar in lower part.	140
	Greer		Massive white gypsum in ledges	10–20
			Red shale	25

Near the mouth of Bonita Creek the dolomite ledge is carried downward under the bed of the river along a synclinal fold, and the upper sandstone and clay members of the Triassic red beds are brought to a lower level, where they form more or less conspicuous bluffs on both sides of the river for several miles. In the vicinity of Ranch and Pedrosa creeks the bluffs are formed by a heavy ledge of sandstone, the lowermost of three heavy sandstone members of the upper formation of the Triassic. The ledge is here approximately 75 feet higher, geologically, than the Alibates dolomite. Near the mouths of Pitcher and East Amarillo creeks the dolomite again appears on the surface along the western limb of the syncline and is exposed along an anticline which extends westward for a distance of about 10 miles up the river. In this locality both the river and its tributary creeks, West Amarillo, Horse, and Tecovas, have cut steep-sided canyons through the dolomite and into the underlying red clays. The height of the Alibates above the river here reaches a maximum of 125 feet on Horse and Tecovas creeks, but is usually considerably less. Pl. VI, *B* shows

A. DAKOTA SANDSTONE HILL.

B. BLUFFS ON CANADIAN RIVER, POTTER COUNTY, TEX.

Showing gypsum lent l at base and dolomite lentil at top of bluffs.

uniform in thickness throughout the region, and in only one locality, so far as observed, have they been entirely removed, so that the Triassic beds rest directly upon the dolomite. This locality is in the western part of the Panhandle, at the mouth of Trujillo Creek, and even here 10 feet or more of the red shales of the upper Quartermaster are locally present.

The Triassic red beds as exposed in the western part of the Panhandle of Texas consist of 150 to 300 feet of shales with interbedded ledges of sandstone and conglomerate. The beds as a whole may be referred to two well-differentiated formations.

At the base of the group are shales known as the Tecovas formation, while at the top are beds composed usually of three ledges of massive, more or less cross-bedded sandstone and conglomerate separated by red shales to which the name Trujillo has been applied. In the following discussion these sandstone ledges will be referred to as the lower, middle, and upper sandstones. The following sections, one on North Branch of North Canyon Cita Creek, a tributary of Palo Duro Creek, and the other on West Amarillo Creek, show the stratigraphy of the Triassic and associated formations.

Geologic section on North Branch of North Canyon Cita Creek, eastern Randall County, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary		Sand and clay	70
Unconformity.			
Triassic	Dockum group. Trujillo	Gray sandstone and conglomerate, cross-bedded, with fossil bones and plates (upper sandstone).	30
		Red and gray shales	35
		Gray cross-bedded sandstone and conglomerate, with fossil bones and plates (middle sandstone).	10
		Red shale with white bands of soft sandstone	60
		Massive, cross-bedded sandstone, gray to brown, with shaly members, and conglomerate, locally three well-marked ledges with shale lentils between (lower sandstone.)	75
	Dockum group. Tecovas	Dark-red shale with white bands	140
		Yellow shales with iron concretions	30
		Maroon shales with iron concretions	20
		White to lavender shales	10
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red shales with white bands and ledges of soft sandstone.	150

Generalized section on West Amarillo Creek, Potter County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Tertiary			Sand and clay	150
Unconformity.				
Triassic	Dockum group. Trujillo		Red clay	30
			Massive sandstone (middle sandstone)	15
			Red shale with thin sandstone ledges	20
			Red or gray massive sandstone and conglomerate, with shale bands (lower sandstone).	25
	Tecovas		Dark-red shales with bands of white and green, near the base some sandstone bands.	50
			Red and yellow shales	15
			Maroon and lavender shales	15
Unconformity.				
Carboniferous (Permian).	Quartermaster		Brick-red shales with sandstone ledges	40
		Alibates dolomite lentil.	White dolomite	2
			Red shale	6
			Massive dolomite	8
			Brick-red shales with white and green bands.	+40

TECOVAS FORMATION.

The Tecovas, the basal formation of the Triassic red beds, as exposed in this part of the State, consists largely of shales. It is divided lithologically into two parts, distinguished by the texture and color of the rocks. Of these the lower is composed of more or less sandy shale of various colors, with maroon, lavender, yellow, and white predominating, and the upper of dark-red or magenta shale. In the following pages these will be referred to as the variegated and magenta shales.

The Tecovas formation, so designated from a creek in Potter County where the rocks are well exposed, rests unconformably upon the Quartermaster beds of the Permian. Its thickness varies in different localities, being 220 feet in Palo Duro Canyon and only 90 feet along Canadian River. It is well exposed in both localities. The following section, on West Amarillo Creek, shows the characteristic stratigraphy of the Tecovas formation in that vicinity:

Geologic section on West Amarillo Creek, 10 miles northwest of Amarillo, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Triassic	Dockum group. Trujillo	Yellow to gray, cross-bedded sandstone (lower sandstone).	15
	Tecovas	Dark-red shale	30
		Yellow shale	15
		Maroon and reddish-brown shale	12
		Lavender shale	10
Unconformity.			
Carboniferous (Permian).	Quartermaster	Brick-red shale	25

The variegated shales lie immediately above the upper eroded surface of the Quartermaster formation, with which they form a vivid color contrast. The shales of the Quartermaster are everywhere a

brilliant brick-red, while the lower Triassic shales are variegated, with white, lavender, maroon, wine color, and yellow predominating. The rocks consist usually of sandy shales, more or less cross-bedded and lenticular, but contain in many localities beds of variously colored soft sandstone. The color of the shale is due largely to the presence of iron, and many dark-colored clay-ironstone concretions weather out at the surface and lodge on the slopes below. The shales are generally hard and firm, weathering into steep slopes with deep V-shaped gullies and sharp intervening ridges.

In general, the variegated shales are composed of three more or less sharply marked zones—a lower zone of white, gray, or lavender; a middle zone of maroon or wine color, and an upper zone of light yellow or sulphur yellow. Usually the colors grade into each other, so that it is difficult to divide the various zones sharply. The thickness of the zones varies considerably even within short distances, and it is not uncommon for shales of a certain color to disappear altogether. For instance, the white or lavender shales at the base of the formation are usually present, but in some localities this zone is wanting and the maroon and wine-colored shales rest unconformably upon the eroded upper surface of the Quartermaster formation. Even where all the zones are present the thickness is subject to considerable variation, as is illustrated in the following table, which includes typical sections showing the thickness not only of the variegated shales, but also of the overlying and underlying rocks at two localities in this region:

Geologic sections illustrating the varying thickness of the variegated shales.

PALO DURO CANYON.

Formation.	Character.	Thickness.	
		Timber Creek.	Canyon City Creek.
		Feet.	*Feet.*
	Magenta shales	150	150
	Variegated shales:		
Tecovas	Yellow	12	20
	Maroon	20	20
	White or lavender	5	10
Unconformity.			
Quartermaster		150	150

WEST AMARILLO CREEK.

mation.	Character.	Thickness.		
		1 mile north of Fort Worth and Denver City R. R.	2 miles south of Fort Worth and Denver City R. R.	1 mile south of Fuqua's ranch.
		Feet.	*Feet.*	*Feet.*
	Magenta shales	75	45	10
	Variegated shales:			
.....	Yellow	10	15	15
	Maroon	10	15	5
	White or lavender	.....	10	10
ty. ter.....		20	20	15

tain localities the variegated shales lose their clayey charac- become largely or entirely sandstone. This sandstone, how- fers so widely in both structure and general appearance from · sandstone found in either the Permian or Triassic forma- the region that it is always easily recognized. In general ite, yellow, or light brown in color, soft and friable, and massive, and much of it contains only a small amount of ng material, so that on exposure it weathers easily, forming rounded or dome-shaped masses, which at a distance bear l resemblance to small buildings. A cluster of these pecul- on forms in the valley of Canadian River on the L. S. ranch, south of Tascosa, is known locally as "Rock City." At the of Trujillo Creek, near the New Mexico line, the variegated re represented by a light-colored soft sandstone with here e a red member, and near the mouth of Bonita Creek, in tern Potter County, by a very similar sandstone. At both the sandstone contains a large amount of fossil wood, being exposed by weathering, lies scattered on the surface. gated shales lying unconformably upon the Quartermaster n are exposed all along Palo Duro Canyon in Armstrong ern Randall counties, where they are easily recognized by l contrast of their maroon and yellow colors with the duller the associated formations. On Canadian River and its es the variegated shales are in some places exposed and in overed by Tertiary wash from the hills. In some localities carried beneath the surface by the synclines. In the east- of the area the variegated shales are exposed at various long Bonita Creek. Near Lee's ranch, north of Canadian he beds are covered, but they appear along both East Ama- l West Amarillo creeks and on Tecovas, John Ray, and creeks farther west. In the vicinity of Tascosa the varie- gales appear at intervals on the surface, being here repre-

sented by the sandstone phase. This phase is also found along Trujillo Creek and several other creeks near the New Mexico line.

The upper part of the Tecovas formation is composed chiefly of shales having a magenta color, which differs materially from the typical brick red of the Quartermaster shale and other Permian red-beds formations and from the lavender, maroon, and yellow of the variegated shales. The thickness of the magenta shale varies in different localities, being 120 to 150 feet in Palo Duro Canyon and 50 to 75 feet on Canadian River.

The magenta shales outcrop along Palo Duro Canyon and Canadian River and their tributaries, appearing between the variegated shales and the heavy basal sandstone of the Trujillo formation. From the rim of Palo Duro Canyon the color contrasts between the magenta shales, the underlying variegated shales, and the Quartermaster beds are very striking. No fossils except the petrified wood are known to occur in the Tecovas formation.

TRUJILLO FORMATION.

The upper part of the Triassic red beds, as exposed in the Panhandle of Texas, consists of several ledges of massive more or less cross-bedded sandstone and conglomerate, with interbedded red and gray shales. These constitute the Trujillo formation, so named from a creek in Oldham County. In most sections there are three well-defined ledges, but here and there the number is increased to five or more by local cross-bedding or by the appearance of lentils. This formation is exposed in Palo Duro Canyon and on Canadian River, as well as on the creeks tributary to both streams. As it is the highest formation of the red beds in the region, it outcrops in many cases at a considerable distance back from the larger streams and near the heads of the creeks. Its upper part shows evidence of extensive erosion, and in a number of localities the highest sandstone member and a considerable part of the underlying shale were removed previous to the deposition of the Tertiary rocks, which lie unconformably upon the Triassic. It is noticeable that in many localities where the Tertiary is thinnest the underlying Trujillo formation reaches its maximum thickness. This is well illustrated in Palo Duro Canyon, where 40 feet of Tertiary rocks overlie 250 feet of the Trujillo, while along Canadian River, where the Tertiary deposits are thick, the Trujillo is correspondingly thin.

Along Palo Duro Canyon and in the valley of Canadian River there occurs near the middle of the Triassic red beds a persistent ledge of massive sandstone which constitutes the lower member of the Trujillo formation. This sandstone is in most places fine grained and massive but here and there it becomes cross-bedded and conglomeratic. In certain localities—as, for instance, in Palo Duro Canyon and its tributaries—the ledge is divided into two or more subordinate beds by the

interposition of shale lentils. In color it is gray or brown, rarely white or red, its subdued tint forming a marked contrast to the more vivid red and variegated shales both above and below. The thickness varies in different localities, having an observed maximum of 60 to 75 feet in Palo Duro Canyon and on Canyon Cita Creek, while on Canadian River it does not average more than 25 feet.

In Palo Duro Canyon and its tributaries the lower sandstone is well exposed as a precipitous cliff, which outcrops about halfway up the canyon wall. So steep is this cliff that it forms an impassable barrier for many miles along the canyon, and in only a few localities are there trails where a horse can be led from the High Plains down into the canyon. In this region the sandstone weathers into peculiar erosion forms, some of the most striking of which are shown in Pl. II, *A* (p. 10). Along Canadian River the sandstone is as a rule well exposed. Owing to its hardness it resists erosion, forms conspicuous ledges, and thus becomes a convenient horizon of reference. Particularly is this true in localities where synclines have carried the underlying beds, notably the Alibates dolomite, beneath the surface, in which case the lower sandstone forms the cap of the bluffs along the river. This condition is well exemplified in northern Potter County on both sides of the river, between the mouths of Bonita and East Amarillo creeks. The best examples, however, are farther west in northwestern Potter and northeastern Oldham counties, where the lower sandstone forms conspicuous bluffs on both sides of the river and on such tributary creeks as Sierra de la Cruz, Parker, Cheyenne, and Alamosa. In localities where the Alibates dolomite forms the river bluff the sandstone above described is found near the head of creeks at some distance from the river.

Separated from the lower sandstone by a bed of red or gray shales 15 to 60 feet thick is a very persistent ledge of sandstone and conglomerate, here designated the middle sandstone. It consists in most places either of coarse, heavy, cross-bedded sandstone, red or gray in color, or of cross-bedded lenticular conglomerate with pockets and lenses of clay. The pebbles which make up the conglomerate comprise various rocks, both igneous and sedimentary, with granite, quartz, sandstone, clay, and limestone predominating. In size they vary from sand grains to fragments 3 to 4 inches in diameter. A few of the pebbles are angular, but the majority are smooth and waterworn. In certain localities almost the entire thickness of the ledge consists of a peculiar conglomeratic clay composed of small fragments of clay or limestone, many of them no larger than a pea, contained in a matrix of sandy clay, the whole having a mottled appearance. As in the case of the lower sandstone, this middle sandstone consists locally of two ledges of conglomerate or sandstone separated by shales.

The thickness of the ledge is variable, attaining a known maximum of 40 feet on South Canyon Cita Creek, while in the valley of the Canadian it averages 10 feet with a maximum of 20 feet. In certain localities along the Canadian and its tributaries the middle sandstone has been removed by pre-Tertiary erosion and does not appear. Its best exposures are found along Palo Duro Canyon and its tributaries, where it forms a persistent ledge 40 to 60 feet above the lower sandstone and along Sierra de la Cruz, Alamosa, and Trujillo creeks, southern tributaries of the Canadian, where it is exposed as a prominent ledge, as a rule near the tops of the hills.

The middle sandstone is the lowest horizon of the Triassic in which fossils have been observed. Remnants of bones and plates were secured from the conglomerate beds or as weathered fragments on the slope below. These specimens were referred to Dr. T. W. Stanton, who reports as follows: "The fossils have been examined by Mr. J. W. Gidley, of the National Museum, who reports that they are fragments of jaw, femur, and skin plates of a belodont, probably *Phytosaurus superciliosus* Cope. The fossils are considered characteristic of the Triassic period."

This leaves little doubt as to the age of the middle sandstone, and as the entire group between the base of the Tertiary and the top of the Quartermaster formation is apparently conformable there is good reason for considering both the Tecovas and Trujillo formations Triassic in age.

Still higher in the Trujillo formation as exposed in this region appears another ledge, here called the upper sandstone. It does not differ lithologically from the middle sandstone. It is a brown to gray, coarse, cross-bedded sandstone or conglomerate with pockets and lenses of clay, which divide the member locally into two or more well-defined beds. The pebbles which make up the conglomerate are composed of clay, sandstone, limestone, ironstone, granite, fragments of bone, etc., closely resembling those of the middle sandstone.

The best exposures of the upper sandstone are in Palo Duro Canyon and its tributaries, particularly along Canyon Cita Creek, where it is 30 feet thick. It is noticeable that in this locality the Tertiary deposits, which in most places on the High Plains attain a thickness of several hundred feet, are relatively thin, being here in places not more than 40 to 50 feet thick. So far as observed the upper sandstone is not exposed on the Canadian or its tributaries, having been carried away by pre-Tertiary erosion.

Fossils similar to those from the middle sandstone are found in the upper sandstone. As in the lower beds, fragments of bones, teeth, plates, etc., occur as parts of the conglomerate, or if weathered out are found on the shale slopes below.

The following sections illustrate the stratigraphy of the Permian,

riassic, and Tertiary rocks of this region. The first section was ıeasured on Timber Creek, one of the tributaries of Palo Duro Creek ı the southeastern part of the area, while the second is from Trujillo reek, a branch of the Canadian in the extreme western part of the anhandle.

Geologic section near the mouth of Timber Creek, eastern Randall County, Tex.

System.	Formation.		Character.	Thickness.
				Feet.
ertiary			Cliffs of sand, gravel, and clay	200
nconformity.				
riassic	Dockum group.	Trujillo	Red and gray shale, with ledges of sandstone	40
			Gray to red sandstone and conglomerate, cross-bedded (middle sandstone).	20
			Red and gray clays and shales	35
			Brown, gray, and red massive sandstone and conglomerate, cross-bedded, with shaly members (lower sandstone).	60
		Tecovas	Dark-red shale	140
			Sulphur-yellow shale, with iron concretions	15
			Maroon shale	25
			White to lavender shale	5
nconformity.				
arboniferous (Permian).	Quartermaster		Brick-red shale, with ledges of soft red or gray sandstone.	150

Geologic section near the mouth of Trujillo Creek, western Oldham County, Tex.

System.	Formation.		Character.	Thickness.
				Feet.
ertiary			Sand, clay, and pebbles	100
nconformity.				
riassic	Dockum group.	Trujillo	Gray to brown sandstone and conglomerate (middle sandstone).	10
			Red shales, with bands of white and blue shale and thin-bedded sandstone.	15
			Heavy brown massive sandstone and conglomerate (lower sandstone).	20
		Tecovas	Clays and soft sandstone; dark-red, yellow, and blue variegated shale; and gray and yellow sandstone, with fossil wood.	90
Unconformity.				
Carboniferous (Permian).	Quartermaster		Red shale and shaly sandstone, unevenly eroded at the top, locally absent.	0–10
			Hard, massive brown to gray, flinty dolomite (Alibates lentil).	15
			Red shales	60
			White gypsum, locally in two ledges separated by red shale (Saddlehorse lentil).	15
			Red shale from bed of Canadian River	20

CRETACEOUS ROCKS.

Exposures of Cretaceous rocks occur in northern and western Dallam County, the northwestern county of Texas, along the valleys of two prairie creeks, Coldwater and Perico. These creeks are, in most places, only shallow draws on the flat Tertiary plains, where erosion has removed the superficial deposits, thus exposing the underlying Cretaceous beds. So far as known, there are only five localities in the county where Cretaceous rocks outcrop.

Near Agua Fria, or Coldwater Springs, in northeastern Dallam County, bluffs composed of brown sandstone and varicolored clays

are exposed for a mile and a half along Coldwater Creek. The following sections illustrate the thickness and varying character of the rocks at this place:

Section 200 yards southeast of Agua Fria Springs, Dallam County, Tex.

	Feet.
Yellowish, white, and brown sandstone	3
Yellow to brown sandstone, cross-bedded, locally becoming shaly	30
Shale, bluish to pink and brown	2
	35

Section three-fourths mile west of Agua Fria Springs, Dallam County, Tex.

	Feet.
Yellowish to brown sandstone	5
White shale	4
Shaly white sandstone	3
Blue clay	1
Brown to chocolate-colored shale	3
	16

At Buffalo Springs, 18 miles northeast of Texline, Tex., half a mile south of the Oklahoma line, there is an exposure of yellow and brown sandstone and clay extending a mile or more along two branches of Coldwater Creek. The following section was made near the junction of the creeks:

Section near junction of forks of Coldwater Creek, Dallam County, Tex.

	Feet.
Tertiary deposits covering slope to top of hill	+50
Sandstone, cross-bedded, yellow, brown, and black; as a rule in beds 8 inches to 1 foot thick	12
White, yellow, drab, and red shales, with thin bands of soft sandstone	20
	+82

Other sections taken near this locality show that the Cretaceous rocks here are composed largely of clay. At the base of the sandstone occur the Buffalo Springs. (See p. 45.) A mile and a half to the north, just across the State line in Oklahoma, there is an outcrop of Cretaceous sandstone approaching quartzite, gray, yellow, or brown in color, which stands out as a prominent rounded knoll 20 feet high and 100 yards in diameter.

Near Texline, on the west line of Dallam County, Cretaceous rocks occur in three localities. On Coldwater Creek, approximately 3 miles south and 2 miles east of the northwest corner of the State, Cretaceous shales and sandstone outcrop for 300 yards or more along the bottom of the creek. On North Perico Creek, 2 miles north of Texline, there is a small exposure of thin-bedded, brown to yellow, more or less cross-bedded sandstone and clay. These deposits, which

nd about half a mile along the bottom of the creek valley, lie
nformably beneath the Tertiary, the base of which here consists
lay and conglomerate, the conglomerate being composed of sand-
ıe pebbles derived largely from Cretaceous rocks. On South
ico Creek, 1½ miles south of Texline, Cretaceous rocks composed of
rnating shales and thin-bedded, brown to yellow, shaly sandstone
ıt 20 feet thick are exposed for about a quarter of a mile.
) far as known, no fossils have been found in either the shale or the
lstone of this part of Texas, nor can continuous outcrop be traced
ther Cretaceous beds the age of which has been definitely deter-
ed. For these reasons exact correlation is not possible. It is
able, however, that the Cretaceous rocks of Dallam County, Tex.,
of the same age as beds which outcrop farther north, west, and
hwest on Cimarron and Canadian rivers and their tributaries in
ern Oklahoma and northeastern New Mexico, where these rocks
ıde part of the Comanche as well as the Dakota.

TERTIARY AND QUATERNARY ROCKS.

GENERAL RELATIONS.

esting unconformably upon the eroded surfaces of the older for-
ons throughout the western part of the Panhandle of Texas is a
s of deposits composed largely of partly consolidated clay, sand,
pebbles of Tertiary age. In former times these Tertiary rocks
ably covered all the older formations, and even now the older
s are exposed only in limited areas, chiefly along valleys where
-continued erosion has removed the Tertiary cover.
eposits of Tertiary age cover the western part of the Great Plains
ı Canada to Mexico. To the greater part of these rocks the gen-
term Loup Fork beds has been applied, and they have been
ed as late Miocene or Pliocene. In Nebraska Darton separates
so-called Loup Fork into the Arikaree and Ogalalla formations,
ming the former to the Miocene and the latter doubtfully to the
cene.[a] Hay and others in Kansas have divided the Loup Fork,
he basis of lithologic character, into "Tertiary grit" and "Ter-
y marl," or "mortar beds." In Texas Cummins and Cope have
inguished the Loup Fork, Goodnight, and Blanco beds, the Loup
ς being Miocene, the Goodnight transitional, and the Blanco
cene in age.[b]
ying upon the Tertiary rocks in many parts of the plains are cer-
Pleistocene deposits, sometimes called the "Equus beds," which
most places do not differ lithologically and can not be distin-

arton, N. H., Preliminary report of the geology and water resources of Nebraska west of the one
red and third meridian: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1899, pp. 932 et seq.
e discussion by the writer in Water-Sup. and Irr. Paper No. 154, U. S. Geol. Survey, 1906, pp. 25-28.

guished stratigraphically from the underlying Tertiary deposits. I the Panhandle it has been found impossible to distinguish strat graphic units in the Tertiary, owing mainly to the fact that the cla sand, and gravel which make up these deposits are arranged heter geneously and without similarity of position. The only possib evidence on which these rocks could be divided into formations paleontologic, and it was on such evidence that Cummins and Cr proposed the formation name mentioned above. Fossils, howeve are rare, and up to the present time no systematic effort has bee made to collect them from various parts of the Great Plains. F these reasons the term Tertiary will be used in the following discu sion to include all the deposits of Cenozoic age which overlie the re beds and the Cretaceous rocks. These deposits include the great part of the rocks of the Panhandle.

CHARACTER OF THE TERTIARY ROCKS.

The greater part of the Tertiary rocks of the High Plains consist clays, sandstones, and conglomerates, with clays largely predomina

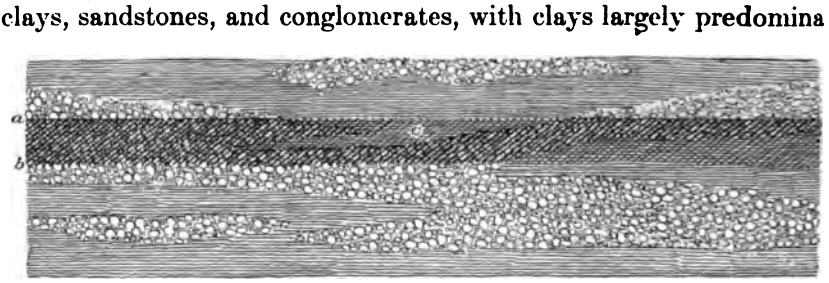


FIG. 1.—Ideal Tertiary structure.

ing. These materials are usually arranged in a heterogeneous manne (see fig. 1), the sand, clay, and other rocks occurring indiscriminatel and without similarity of position from place to place. As a rule th coarser materials, such as sand and pebbles, lie near the base of th Tertiary deposits, immediately above the red beds or Cretaceou rocks, while the finer clays and silts occupy a position higher up in the system. Not uncommonly this order is reversed and clays lie directly upon the eroded Permian or Triassic red beds and below strata composed of Tertiary gravel.

The clays are white for the most part, but here and there pink or buff. The various tints are uniformly subdued, however, so that from a distance the Tertiary cliffs appear to be white and are locally known as "chalk" cliffs or "gyp" cliffs, although they contain neither chalk nor gypsum. The clay is generally a soft, homogeneous mass, but it contains indurated beds, which are in places sufficiently calcareous to make good limestone. Not uncommonly these harder layers appea at regular intervals in the softer clays, and the slope on weatherin assumes a peculiar "stair-step" appearance, having locally the form

river terraces. All the clays contain lime in greater or less quantities and in many beds there are white calcareous concretions, which give to the rock a mottled appearance, a fact particularly noticeable where the clay is pinkish or buff in color. In many places the lime cements the clay together in the form of elongated "pipy" concretions, or in irregular and grotesque forms which, being harder than the clay, may be left standing when the latter is eroded.

The sand which makes up a considerable proportion of the Tertiary deposits is composed largely of smooth, rounded white or yellow quartz grains. Locally it is cemented by lime into coarse, rough sandstone, but it is more commonly unconsolidated and in many places where erosion has removed the soil it is blown by the wind into dunes. In many instances the sand occurs in beds mingled with small pebbles and clay cemented with lime, forming the so-called "mortar beds" of the Kansas geologists.

The conglomerate of the Tertiary is made up mainly of smooth, rounded, waterworn pebbles of granite and other igneous rocks, though sandstone, limestone, and clay pebbles are present in numerous places, the latter being particularly abundant near the base of the deposits. These pebbles vary greatly in size, shape, and color. In size they range from small sand grains to bowlders 6 inches in diameter; in shape they are, as a rule, more or less rounded, though some are flattened, oval, elongated, or subangular; in color they are most commonly gray, pink, black, yellow, red, or brown, depending on the character of the rock from which they were derived. These pebbles occur generally in more or less lenticular, cross-bedded layers, some of which are 50 feet thick or more, but in many places they are interjungled with fine sand, and locally are scattered through the clay members. The conglomerate is more abundant at the base of the Tertiary, where it forms many conspicuous ledges, as, for instance, near the mouth of Ranch Creek, north of Canadian River, in northern Potter County, where bluffs 100 feet high are composed entirely of coarse, cross-bedded conglomerate.

As the Tertiary rocks are removed by erosion the pebbles weather out and cover the slopes. They are rarely found on the level surface of the High Plains, but appear on their eroded eastern slope, and are thick on the low, rounded hills and bluffs near the larger streams. Near the base of the Tertiary, waterworn *Gryphæa* shells of Lower Cretaceous age are sometimes found scattered among the pebbles. These shells were evidently derived from the Cretaceous beds known to occur farther west and were deposited in their present positions at the same time as the Tertiary material.

It is impossible to do more than roughly estimate the proportions of the various rocks composing the Tertiary deposits, for, as has been stated, there is constant local variation. It appears probable, how-

ever, that throughout the region as a whole from two-thirds to three-fourths of the Tertiary material is composed of some form of clay or silt, the remainder being sand or pebbles. In Nebraska and Kansas, to the north, and in Oklahoma, to the east, the proportion of the coarse material is relatively larger.

ORIGIN OF THE TERTIARY ROCKS.

The question of the origin of the Tertiary deposits on the Great Plains has occupied the attention of American geologists for more than fifty years. The thickness of the deposits, their wide areal distribution, and the paucity of fossils in the beds have combined to present unusual difficulties in the solution of the problem.

Two general theories have been held regarding the method of their deposition. It was believed by the earlier geologists that they were laid down in the bottom of a vast inland lake. Marsh described a great Pliocene lake covering practically the entire Great Plains area, in which deposits 1,500 feet thick were laid down. Both Cope and Cummins refer to the Texas Tertiary beds as "lacustrine terranes" or "lake deposits." Hay and others accepted the lake theory to account for the deposition of the Kansas beds. At the present time, however, the consensus of opinion among those geologists who have studied the formations in the field is that the Miocene and Pliocene deposits on the Great Plains are due to fluviatile rather than to lacustrine agencies. To quote but two of several authorities on the subject:

> The relative positions of the sand, gravel, and clay of the Tertiary over the whole of Kansas * * * correspond much better to river deposits than to lake deposits. The irregularity of formation succession, the limited lateral extent of the beds of gravel, sand, and clay, and the frequent steepness of the cross-bedding planes all correspond to river deposits. * * * The materials themselves have many indications of river deposits and very few of lake deposits.[a]

> The structure—an uneven network of gravel courses and elongated beds of sand penetrating a mass of silt and sand-streaked clay—is the normal product of desert-stream work under constant desert conditions. The coarse material is not regarded as the product necessarily of strong-running streams and the fine material of sluggish streams in alternating epochs either of humid and dry climate or of high and low inclination of slope, but as the simultaneous product of branching streams of the desert habit, here running in a channel and there spreading thinly.[b]

So far as the writer has been able to ascertain, few, if any, of the more recent investigators accept the theory of lacustrine origin for the Tertiary deposits of the Great Plains. Practically the only point at issue is whether the source of the indiscriminate, uneven, or lenticular deposition of the material by the streams should be sought in climatic changes which produced alternate periods of aridity and humidity or in extended deformation of the earth's crust by which

[a] Haworth, E., Physical properties of the Tertiary: Second Ann. Rept. Kans. Univ. Geol. Survey, 1897, p. 283.

[b] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 655.

e eastern part of the Great Plains was at times elevated and again pressed, giving rise to alternating steepening and lessening of the adient of the streams. It seems possible that each of these causes ay furnish a partial solution of the problem.

SAND DUNES.

Sand dunes occur in many parts of the Great Plains. Almost invariably the material which makes up these dunes is derived from either he Tertiary deposits or the "Equus beds." As the Cenozoic deposits, which, as above stated, are composed of rather loose, unconsolidated clay, sand, and conglomerate, are eroded, the finer clay and silt are carried away, either in suspension or in solution, and the sand which remains behind is blown by the strong prevailing winds into dunes, many of which cover considerable areas. In central and western Nebraska, for instance, thousands of square miles are occupied almost exclusively by them. Dunes are also common in western Kansas and eastern Colorado and cover considerable areas in the eastern part of the Panhandle of Texas and of western Oklahoma.

In the area described sand dunes are relatively rare, being found chiefly along the breaks of Canadian River. In northeastern Potter County along Chicken and Bonita creeks there is an area of 20 square miles or more containing dunes, some being of considerable size, many of which are barren of vegetation. North of Canadian River a strip of sandy country, in which numerous dunes occur, extends from the head of Big Canyon and Big Blue creeks westward for 20 miles. Dunes are also present over parts of western Oldham, Hartley, and Dallam counties near the New Mexico line and in a relatively small area near the Oklahoma line along Beaver Creek in northern Sherman County.

ALLUVIUM.

Along Canadian River and its tributaries and to a less degree along the waters of Palo Duro Canyon there is a considerable amount of alluvium or valley wash. This material, which is composed largely of more or less modified Tertiary and red-beds deposits naturally partakes of the character of the rocks from which it has been derived. Where it comes mainly from the red beds it consists, as a rule, of a reddish clay loam, and where derived from Tertiary deposits it is normally a light to dark sandy loam, the color depending largely on the amount of organic matter present. In many places the alluvium grades imperceptibly into beds of sand, which if blown by the wind may form dunes. In the valley of the Canadian the alluvium occupies the flat flood plain between the bluffs, which averages from 1 mile to 2 miles in width. In Palo Duro Canyon and other smaller creeks the alluvial valley is narrower, varying in width from a few rods to half a mile or more.

WATER RESOURCES.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

Most of the underground water in the western part of the Panhandle of Texas is derived from the Tertiary deposits, which, as has been stated, constitute the greater part of the surface rocks of the region. Along the valley of Canadian River and in Palo Duro Canyon water is found in the red beds, and in the extreme northwestern part of the State there is a small area where the water in both wells and springs is derived from Cretaceous rocks. With these minor exceptions, however, the Tertiary beds are the source of all the water in the region.

Water which has its source in Tertiary rocks is almost uniformly soft and relatively pure and is suitable for all domestic uses. Analyses of a large number of samples taken both from springs and wells in various parts of the Great Plains reveal little or no harmful salts. Relatively small quantities of lime, gypsum, soda, and a few other salts are locally present, but the average amount rarely exceeds 10 grains per gallon, so that for all practical purposes Tertiary water may be considered pure. Water from the red beds is in some cases pure and in others not, according to the character of the rocks from which it is derived.

WATER FROM THE PERMIAN RED BEDS.

Most of the water which has its origin in the Permian red beds contains a large amount of the various mineral salts which enter into the composition of these rocks. The most common of these are calcium sulphate (gypsum), calcium carbonate (limestone), magnesium sulphate (Epsom salts), sodium sulphate (Glauber's salts), sodium chloride (common salt), sodium bicarbonate (soda), sodium borate (borax), magnesium chloride, magnesium carbonate, and calcium chloride. In the valley of Canadian River and its tributaries the water from many of the springs which issue from beneath the Alibates dolomite or the Greer or Saddlehorse gypsum ledges is so highly mineralized that it is unfit for use. Many wells which obtain their supply in these formations (as, for example, the two deep wells on the L. S. ranch, near Tascosa) contain hard water. There are, however, many springs in the Quartermaster formation, both on Palo Duro Canyon and along the Canadian, which yield soft water. In general, the water from the Permian red beds is slight in amount.

WATER FROM THE TRIASSIC RED BEDS.

Springs in the Triassic red beds occur both in Palo Duro Canyon and along Canadian River. Those in Palo Duro Canyon and along Timber, Sunday, Canyon Cita, and other tributary creeks usually issue from under the various sandstone ledges which occur in the Trujillo formation. Springs are also found in the Triassic beds on Canadian River and its affluents, particularly on Tecovas, Sierra de la Cruz, and Alamosa creeks, where in many places the water issues from joints and fissures in the red clay and also from beneath sandstone ledges. As a rule water from springs in the Triassic is fresh and pure, owing largely to the fact that Triassic rocks contain very few harmful salts.

Few wells have been sunk in the Triassic formations in this part of the State. In several instances, however, wells which were started in the Tertiary penetrated the upper beds and obtained water in the Triassic. Wells of this character occur on the High Plains near the edge of Canyon Cita Creek. A few wells on the divides between creeks which empty into Canadian River obtain water from the Triassic beds, the water in almost every case being soft and relatively pure.

WATER FROM CRETACEOUS ROCKS.

The Dakota sandstone, which is one of the great water-bearing formations of the Great Plains, outcrops along a line extending from Minnesota to New Mexico, as well as along the Rocky Mountain front range. In most regions where the Dakota is exposed springs are numerous, and wells sunk into the formation furnish an abundance of water. Almost without exception the water from the Dakota is good. In the northwestern part of the Panhandle there are two large springs in the Dakota sandstone, Agua Fria and Buffalo, both of which are located on Coldwater Creek in northern Dallam County. Buffalo Springs flow approximately 5 second-feet. Wells in this part of the State which are begun on the Tertiary-covered plain pass through the upper beds and find an abundant supply of water in the Dakota sandstone. The wells are comparatively shallow, so that the region is known locally as the "shallow-water district."

WATER FROM TERTIARY ROCKS.

Occurrence.—In order to understand underground-water conditions, it is necessary to know the geologic structure of the rocks from which the water is obtained. In the Panhandle of Texas, as has been stated, by far the greater part of the water comes from Tertiary rocks, and for that reason a brief discussion of the origin and structure of these rocks will be given here.

The Tertiary rocks found in the Panhandle consist of deposits in most places several hundred feet thick, made up chiefly of alternating, more or less lenticular, or cross-bedded layers of clay, sand, and gravel, the latter being composed mainly of smooth, rounded, waterworn pebbles. There seems little doubt that the original material of these deposits was derived largely from the Rocky Mountains. Streams which flowed away from the mountains carried material out on the plain and left deposits in some places of sand, in others of clay, and in still others of gravel or pebbles, which in turn were covered by other deposits, here and there the same, but more commonly of other material. This process, which continued for a long period, resulted in the accumulation of several hundred feet of alternating beds of irregularly stratified rock. Being laid down under such conditions the Tertiary series as a whole is necessarily composed largely of beds irregularly lens-shaped in cross section and in most cases not continuous over large areas. In some localities the greater part of the thickness may consist of fine materials, while in others sandstone and gravels may predominate; but in general the beds of fine and coarse material are mixed in a heterogeneous manner.

The terms "sheet water" or "underflow" are often used in the States of the Great Plains to indicate any fairly constant supply of water at a more or less uniform depth. The general impression seems to be that at some depth beneath the surface there is a continuous "sheet" or "lake" of water which if tapped by a well will yield a fairly constant supply. In some places two or even three such "sheets" are supposed to exist, and the expressions "first sheet" and "second sheet" or "first water" and "second water" are common. Another prevalent notion is that the water in these "sheets" is constantly flowing streamlike beneath the surface, an idea disclosed by the common expression that the "underflow is to the east."

While it is true that these popular ideas are widespread and in general are based on common observation, there is, however, in them much that is erroneous and not based on a correct conception of the conditions found in the nature and relations of the water-bearing strata. Rounded grains of sand and gravel such as make up the lenticular beds which constitute the majority of the Tertiary rocks do not lie closely enough together to fill all the space, but have very small interstices between them. These pores or spaces are minute reservoirs for the water, which in its passage through such materials either vertically or laterally seeps from one of these minute reservoirs to the next, and thus very slowly flows along underground. This movement is popularly called "underflow," but it is not nearly so rapid as is commonly supposed. A number of experiments have been made on the rate of flow of underground waters, and it has been found that even along stream valleys, where the material is coarse, the pores large, the gradi-

ent relatively steep, and all conditions favorable for a rapid flow (as, for instance, along Arkansas River in western Kansas), the rate of underflow does not average more than 10 feet a day.[a] On the High Plains, such as constitute the region under discussion, where the gradient is low, much of the material fine, and the pores relatively small, and where the lenticular beds dip in many places at different angles in different directions, it is doubtful if on an average the water moves more than 10 feet in a year.

According to the theory just advanced dry ground is ground in which the pores between the rock particles contain no water, while wet or saturated ground is that in which the pores are filled. Since water always tends to sink to the lowest levels, there is in most regions a certain but variable thickness of beds filled with water in what is technically known as the "zone of saturation." The upper surface of this zone of saturation is called the "water table" or "water plane," and this is in many places identical with what is meant by the popular phrase "sheet water," so common on the Great Plains. Since water moves slowly underground, this water table becomes approximately similar in contour to the surface of the ground, being high on the divides and low near the streams, where the water may escape in springs.

As originally deposited the lenticular beds which constitute the greater part of the Tertiary deposits must have had an irregular outline and surface, especially where they were laid down in swamps or lakelets. Where the material is clay or very fine sand the interstices between the particles are very minute and practically impervious to water. Fine deposits such as those just described are in numerous instances overlain by sand and gravel which was originally laid down in basins or channels, and these in turn by other fine-grained deposits in varying succession, so that the alternation of water-bearing and impervious beds is, in many places, very irregular. If deposits of this nature are penetrated by a well, the first sand encountered will furnish water, the quantity depending on the size of the water-bearing deposit, the coarseness of its grains, the height of its edges, etc.; in the next coarse sand bed a second water stratum will be found, and so on, until finally the main water table is penetrated. This may be considered a probable explanation of the "first and second water" or "first and second sheet" so often spoken of on the Great Plains. It also possibly accounts for conditions found in many parts of the region where records obtained from a relatively small area show well depths varying up to a hundred feet. These conditions are set forth in fig. 2.

[a] Slichter, C. S., The motions of underground waters: Water Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 41-43.

In general the average depth of the wells in any particular locality may be considered the approximate depth of the water table at that place. As will be understood from what has been stated, the water-table, or the level at which the top of the ground water stands, varies constantly from place to place, from year to year, and even from day to day. It is supplied chiefly from rainfall and is lowered whenever the water is removed—as, for instance, by springs, artesian wells, or heavy pumping. Ordinarily the water table is at a considerable distance below the surface, but here and there it reaches the surface level, as in springs, swamps, or marshes.

On the High Plains the water table is located at the upper point of saturation of the pervious beds. Well records from widely separated localities show that this water level for the High Plains as a whole averages from 200 to 250 feet beneath the surface. So far as known, this level in each locality is fairly constant, the amount of water taken away by springs and wells being approximately equaled by the amount added each year by precipitation.

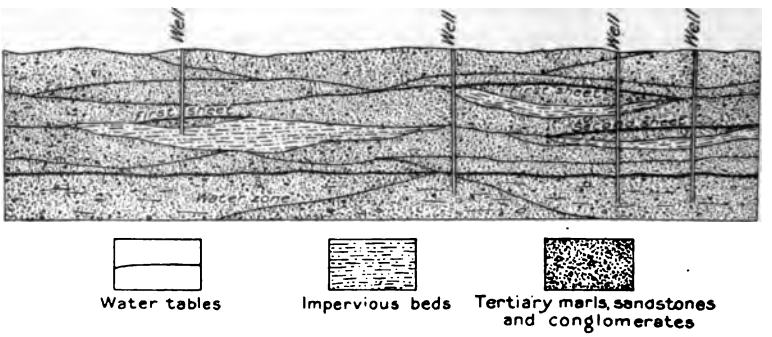


FIG. 2. Ideal Tertiary structure showing water-bearing beds at different levels.

In the area described the depth of the wells in the Tertiary deposits of the High Plains varies from 50 feet to more than 400 feet. On the High Plains north of Canadian River the deepest wells (which are in eastern Dallam County) are between 400 and 450 feet deep, while in Moore and Sherman counties they do not average more than 250 feet. South of this river, on the Llano Estacado, the deepest wells are in the eastern part of Potter County, where water is occasionally found at depths exceeding 400 feet. In Deaf Smith and Randall counties, in the southern part of the Panhandle, the wells are shallower, in many localities not averaging more than 75 feet; in the vicinity of Hereford, the county seat of Deaf Smith County, many of the wells are not more than 60 feet deep.

Sources.—There is a prevalent but erroneous idea in most parts of the High Plains that the water which supplies the wells on the plains comes from the Rocky Mountains. That this can not be true is very evident to any one who has studied the geologic structure of the plains

as a whole. All available data point to the fact that local precipitation is the only source of the underground water of the High Plains. This subject is discussed more fully under the head of artesian water (pp. 42–43).

Rainfall on the surface of the earth is disposed of by evaporation, run-off, and percolation. It is estimated that in general the amount of water disposed of in each of the three ways is about equal, but the relative amounts in different regions depend on several local conditions; for instance, on a steep slope or in a region of stiff clay soil the greater part runs off; in a warm, arid climate the greater part evaporates, while in loose soil the greater part is absorbed.

Throughout a considerable part of the Great Plains, where the surface is level and the drainage systems undeveloped, there is no run-off and all the rainfall is either absorbed or evaporates. After a rain the greater part of the water soaks into the ground, and the remainder, which does not evaporate immediately, accumulates in broad shallow depressions on the surface, known as buffalo wallows or lakes, in which it remains until it evaporates or disappears beneath the surface. Johnson estimates that not more than 3 or 4 inches of rain annually sinks into the ground,[a] an amount which would not saturate more than about 1 foot of sandy strata. This estimate of the amount of water absorbed seems to the writer to be rather small, but in all probability the rainfall does not add more than 18 inches to the ground water each year. An amount approximately equal is lost through springs and wells, so that in general the level of the water table remains constant. There are no data which would lead to the inference that the amount of water is either increasing or decreasing

WINDMILLS.

In a country such as the Panhandle of Texas, where water is practically everywhere abundant in wells, but occurs at considerable depths beneath the surface, one of the most vital problems is that of finding a relatively cheap and efficient means of bringing it to the surface. For this purpose the ordinary force pump is almost universally used. In a few shallow wells along stream valleys or among the breaks a rope and bucket are employed to supply water for household use, but it is safe to estimate that 99 per cent of the wells in the Panhandle are provided with a pump. Power is usually furnished by windmills, of which several forms are employed, by far the greatest number being of the ordinary turbine type. On the larger ranches, particularly where water is deep and it is necessary to raise considerable amounts for cattle, a wooden wheel from 16 to 20 feet in diameter, mounted on a relatively low tower, and a 3-inch pump are usually

[a] Johnson, W. D., The High Plains and their utilization: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 646.

employed, while on smaller ranches and farms and in the towns an iron wheel is generally used.

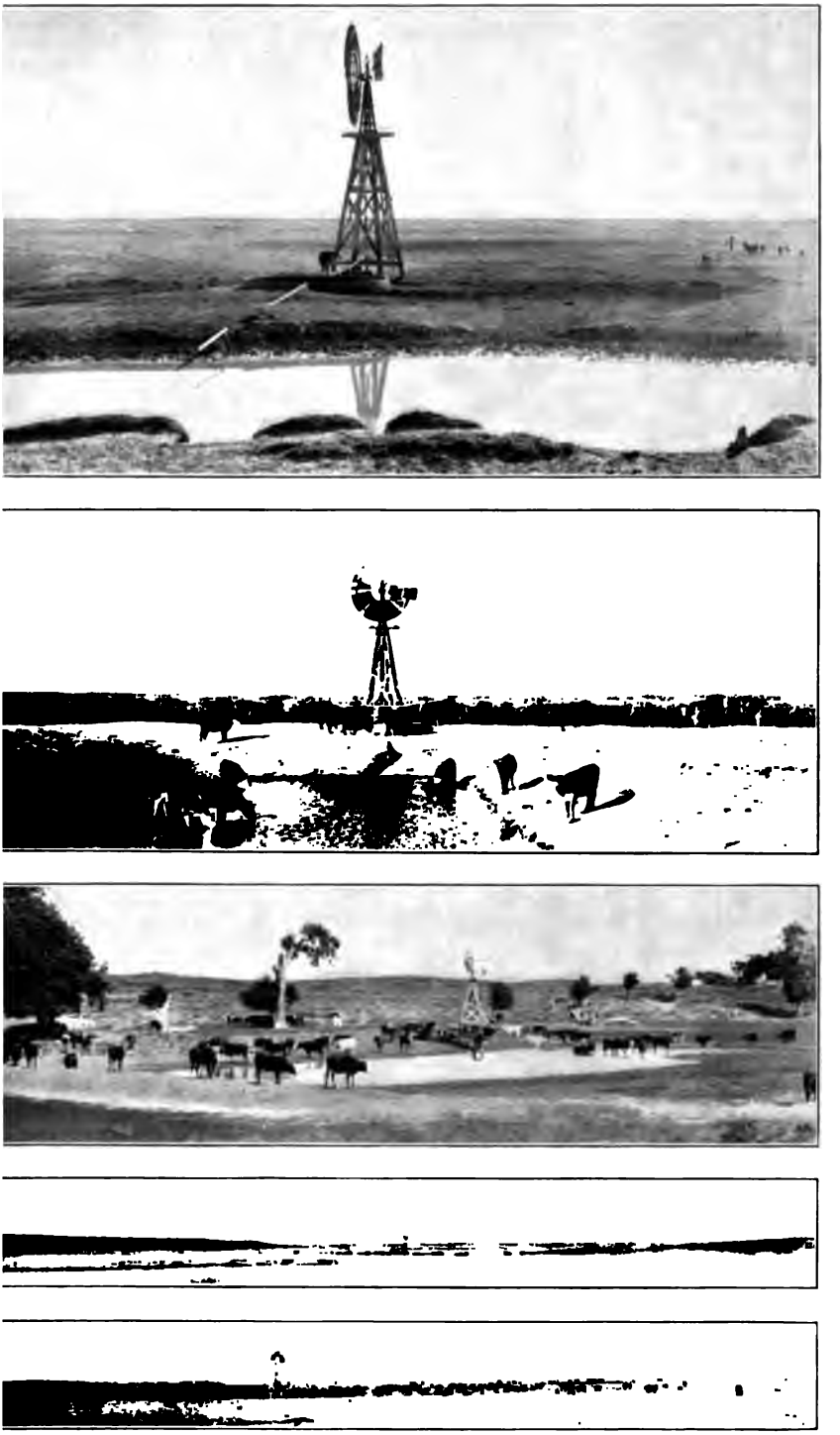
On the larger ranches, where thousands of cattle graze, it is necessary to provide a constant and convenient supply of water, and for this purpose wells have been put down at intervals of 2 to 3 miles in all directions. In many parts of the prairie the only evidence that the country is inhabited is furnished by a lone windmill, surrounded at certain times of the day by herds of cattle. The water is pumped from the well into large circular tanks of wood or iron, to which the cattle have access. In many instances there is an arrangement whereby when the tank is full the overflow passes into an earthen reservoir which has been excavated near by, the object being to provide an emergency supply in case the wind does not blow for several days. Rarely do extended periods of calm occur, however, and the windmill once set going is never stopped until it wears out. On the larger ranches men known as "windmill greasers" are employed, who do nothing but oil and repair windmills. Two men usually travel together, camping out wherever night overtakes them, visiting each mill on an average of twice a week.

In the Panhandle of Texas it is usually estimated that the cost of sinking a well and installing a mill, pump, and tanks averages about $2 a foot for deep wells and a relatively larger sum for shallower ones. In localities where the wells are 400 to 500 feet deep the cost of the well, mill, pump, and tanks complete is $800 to $1,000, while if the well is but 100 feet deep the cost is $250 to $300. Pl. VII shows characteristic windmills on the plains.

DEEP-SEATED WATERS.

In the various parts of the Panhandle of Texas the project of obtaining artesian water is often considered. There is perhaps not a county in which the subject has not been agitated, and as the country is now being rapidly occupied by settlers it is altogether probable that a number of attempts will be made in various localities to secure an artesian supply. In most cases, as above stated, it is assumed that the water found in the wells of the High Plains comes from the Rocky Mountains. But this is not so. The Llano Estacado, or that part of the plains south of the Canadian, is cut off from the mountains by the valley of this stream and by Pecos River in eastern New Mexico, so that it is impossible for water to pass from the mountains into the Tertiary beds which carry the water on the High Plains. North of the Canadian the Tertiary deposits thin out to the west and disappear before the Rocky Mountains are reached, so that the probability of any extensive artesian flow, having its origin in the Tertiary beds in this part of the country, is very small.

There are a few artesian wells in the region, as for instance, one on



HIGH PLAINS WINDMILLS

ig Blue Creek in eastern Moore County. This well, which is 123 feet ep, flows about 1 gallon per minute. From the record obtained it ppears that the well passed through 25 feet of Tertiary clay and then ntered the red beds. The water was found in a sandstone, possibly one f the members of Trujillo formation, in the upper part of the Triassic ed beds. It is probable that the supply of water in this well is gov-rned by local conditions, and that while other similar wells may be leveloped here and there their number will never be sufficiently large o be of economic importance. There are a number of other wells long Big Blue Creek that find water at about the same depth, but one of them flow. An artesian well is reported on Rita Blanca Creek, west of Channing. The supply is limited and the well is not important.

At the L. S. ranch, 2 miles west of Tascosa, at an elevation of 3,160 feet, there are two artesian wells a quarter of a mile apart which draw their supply of water from the red beds. The wells are of equal depth, approximately 340 feet, and the water from each fills a 5-inch pipe. The water, however, contains so high a percentage of mineral salts that it is unfit for domestic use. These wells are located in one of the synclinal troughs described on page 20, and the source from which this water derives its head is probably located along the anticline to the west, possibly in the vicinity of Trujillo Creek. As this syncline extends 30 miles or more up and down the river there is a possibility that more extensive drilling might result in a number of such wells in the red beds along the Canadian in this region. The source of the water is probably in the Permian red beds, somewhere about the horizon of the Greer gypsum, and it is very likely that the water from any wells in this locality would be so highly mineralized as to be undesirable for either domestic use or for irrigation. Fortunately this district is traversed by a number of flowing streams, so that there is no particular need of resorting to wells for stock water.

In the northwestern part of Dallam County, where the Dakota sandstone approaches the surface, it is possible that artesian water might be obtained. It is reported that a well, drilled in 1888 on the high divide near Coldwater Creek, 6 miles north of Texline and 3 miles from the northwest corner of the State, reached a depth of 1,250 feet and that the water stands within 100 feet of the surface. The record can not be had, but it is probable that this well penetrated both the Tertiary and the Dakota and stopped in the red beds. The water may come from the Dakota sandstone.

SPRINGS.

GENERAL CHARACTER.

The springs in the western part of the Panhandle of Texas may be classed under three general heads, according to the geologic formation from which they are derived—red-beds springs, Cretaceous springs, and

Tertiary springs. The red-beds springs are usually found in the valleys of the larger streams, such as Canadian River and Palo Duro Creek. The water is in some places pure and in others not, depending on the amount of mineral salts contained in the rocks from which the spring issues. The water from Cretaceous springs, which are found in Dallam County only, is always good. Tertiary springs are by far the most important, with regard to both number and amount of water, and the water is almost uniformly fresh.

RED-BEDS SPRINGS.

Springs from the Permian red beds are found chiefly in the valley of Canadian River, although a few are known to occur in the deeper parts of Palo Duro Canyon and its tributaries. In the latter locality the water usually issues as seeps from the argillaceous sandstone of the Quartermaster formation along some small canyon or gully. Farther east, in Oklahoma, the Quartermaster formation is more sandy and is noted for its large number of small springs. In Palo Duro Canyon, however, there is a larger amount of shale in the formation and the number of springs is not so great.

In the valley of the Canadian and its tributary creeks Permian red-beds springs are often found. In the eastern part of the region, particularly on Big Blue, Plum, Big Canyon, Turkey, and Alibates creeks, many springs issue from beneath the massive ledges of the Greer gypsum, the water of which is strongly impregnated with calcium sulphate and other salts. The majority of the springs, however, come from the Quartermaster formation and many of them issue at the base of the Alibates dolomite lentil. Springs of this character are found on all the creeks named above and also on West Amarillo, Horse, Tecovas, Las Achias, Trujillo, and others. These springs usually issue as bold, gushing streams at the point of contact between the dolomite and the underlying clay. Seep springs issuing from the sandy beds of the Quartermaster are also common in this region. Many of the springs from below the dolomite ledge contain appreciable amounts of mineral salts, so that the water is undesirable for ordinary domestic use, while the water of seep springs from the sandstone is usually soft and pure.

Springs from the Triassic red beds are found both in Palo Duro Canyon and in the valley of Canadian River. Along Palo Duro Creek and its tributaries they issue as a rule from beneath the various sandstone members of the upper or Trujillo formation, although springs in the Tecovas shale formation are not uncommon. On Canyon City Creek springs issue from beneath all three of the sandstone members of the Trujillo formation, while in the main canyon, a few miles east of the falls, there are strong springs which issue from joints in the magenta shales. The water from the Triassic sandstone in Palo Duro

anyon is generally soft and pure, but because of the inaccessibility f the springs it is not utilized. In the valley of Canadian River prings occur in the Triassic, not only near the river where it has cut rough the rocks of this series, but also on the tributary creeks—ast Amarillo, West Amarillo, Tecovas, Sierra de la Cruz, Parker, lamosa, Alamositas, Las Achias, and Trujillo. In some places the ater issues from beneath the lower or middle sandstone of the Truillo, in others from joints in the clay, and in still others from the sandtone which in this region locally takes the place of the variegated hales of the Tecovas. Some of the springs are strong and some mere eeps. The water is almost invariably soft and suitable for housecold use.

CRETACEOUS SPRINGS.

In the Cretaceous rocks of the Panhandle, which, as has been stated, ccur only in limited areas in the extreme northwestern part of the tate, there are two springs worthy of note. Both are situated in the alley of Coldwater Creek near the northern part of Dallam County.

Agua Fria Springs are located about 10 miles west of the Sherman ounty line. At this place Coldwater Creek has cut through the ertiary deposits, here comparatively thin, and for 35 feet into the rownish-yellow Cretaceous sandstones and clays, which are exposed or 1½ miles along the creek. At several points in this distance the ater issues from the bottom of the creek and collects in pools, nally forming a running stream.

Much more important from an economic standpoint are Buffalo Springs, which are located 17 miles east of the northwest corner of the State, at the point where two branches of Coldwater Creek unite. The stream has cut through the Tertiary deposits, exposing the Cretaceous sandstone and clay along both branches. Here a number of strong springs issue near the bottom of the valley. Their waters unite to form a stream which flows approximately 5 second-feet and which is utilized to irrigate 150 acres of alfalfa, garden, and trees. When not used for irrigation the water from the springs is allowed to run down the creek, and is sufficient to flow for 5 to 8 miles along the sandy channel before finally disappearing.

TERTIARY SPRINGS.

By far the most numerous and also the most important of all the springs in the Panhandle are those in which the supply of water comes from Tertiary rocks. These springs occur at numerous points along the edge of the High Plains where the water-bearing beds are exposed and in practically every ravine and canyon that has cut its way through the Tertiary deposits and into the underlying formations. The greater part of the springs are contact springs, issuing at the

point of unconformity at the base of the Tertiary. If a well on the level plain penetrates a saturated zone, water is obtained, and if a stream in its downward cutting encounters the same zone a spring will result, as shown in fig. 3. So it happens that many of the small streams which are cutting their way headward into the High Plains in all directions encounter these water-filled gravel and sand beds in the Tertiary and permit the water to escape to the surface as springs. These springs are found in all parts of the Great Plains from Canada to Mexico and have played an important part in the economic development of the region. Numerous farm houses, ranches, factories, forts, and towns throughout this part of the United States have been located with reference to some Tertiary spring.

Tertiary springs are found in all parts of the Panhandle except on the level surface of the High Plains and in the bottoms of the larger stream valleys. In the southern part of the area both Palo Duro and Tierra Blanca creeks are fed by springs which issue from sand beds along the low bluffs near the bottoms of the valleys. Near the point where these creeks unite at Canyon each has a flow of approximately

FIG. 3. Ideal section of Tertiary springs. *A*, *D*, Tertiary springs; *C*, *F*, wells in red beds; *E*, well in Tertiary.

15 second-feet. As the canyon deepens numerous small branches, which rise on the level plain and cut their way downward through the Tertiary rocks, reach the zone of saturation and springs result. This condition is well illustrated on the head branches of Timber and Sunday creeks and on both North and South Canyon Cita creeks.

Practically every stream which enters Canadian River in this region is fed by Tertiary springs, but only the principal spring-fed creeks and a few of the most important springs can be mentioned.

North of Canadian River, Tertiary springs occur in considerable numbers along Big Blue Creek in eastern Moore County. They are also present on Plum and Big Canyon creeks, although not in large numbers, because these streams flow for the greater part of their course through the red beds. Ranch Creek is a perennial stream fed by Tertiary springs. Near Lee's ranch, 20 miles north of Amarillo, several strong springs issue from Tertiary sand wash in the valley of the Canadian. Pitcher Creek, though a relatively short stream, carries sufficient water to irrigate 50 acres of alfalfa, the entire amount being supplied by Tertiary springs. John Ray, Lahay, India, Corral, Sand, Casino,

l Tascosa creeks are all fed by springs which issue near their heads the base of the Tertiary. The amount of water, however, is rarely ficient to keep the streams flowing continuously, and most of se creeks are dry sand beds for the greater part of the year. The wn of Tascosa is supplied with water from a spring which issues m the Tertiary sand a short distance away. On Cheyenne Creek a ke has been formed by the construction of a dam across the stream, d the water is conveyed by gravity to the railroad station at Ma-nta, where it is used by locomotives. On Rita Blanca, Moneto, inneosa, and several other smaller streams which enter the Cana-an from the north, in the western part of the Panhandle, a number strong Tertiary springs issue from the top of the red beds.

The creeks which empty into the Canadian from the south are lso fed by springs which issue from the red beds and Tertiary con-ct along the northern edge of the Llano Estacado. In the eastern art of the region Turkey and Alibates creeks are supplied near eir heads by Tertiary springs, but the water sinks into the sand efore reaching the river. Chicken Creek is fed by springs which sue from sand dunes. Bonita Creek, which is supplied by Tertiary prings, flows a steady stream throughout the year, while Pedrosa reek, a few miles farther west, receives water from a much smaller umber of springs and is in consequence a dry sand bed. Both ast and West Amarillo creeks receive water from Tertiary springs, s do Tecovas, Sierra de la Cruz, and Parker creeks, although in one of these streams is the amount of water sufficient to form a nning stream all the year. Along the heads of the various ranches of Alamosa Creek there are many Tertiary springs, near ne of which is located the old L. S. ranch. On Skunk Arroyo and lamositas Creek there are also numerous springs, some of which ave a flow of nearly 1 second-foot. The spring at the old X I T eadquarters, on Alamositas Creek, has been used for irrigation for number of years. Springs occur at the foot of the plains on Las chias Creek and on the various tributaries of Trujillo Creek, par-cularly Agua Piedra and Mujeres.

STREAMS.

The drainage of the Panhandle of Texas flows into Mississippi iver. The extreme northern part is drained into Beaver Creek, ne of the head tributaries of North Fork of Canadian River, and ne central part is crossed by Canadian River. These two streams ow eastward across Oklahoma and unite before entering Arkansas iver. The water from the southern part of the region flows into alo Duro Creek, one of the head tributaries of Red River.

NORTH FORK OF CANADIAN RIVER.

Beaver Creek flows for 15 miles in a broad bend to the south in the northern part of Sherman County. It is here a dry sand bed for the greater part of the year.

Coldwater Creek flows from New Mexico into Texas and passes eastward across the northern part of Dallam and Sherman counties before turning to the north to enter Beaver Creek in Oklahoma. For the greater part of its course in the counties named Coldwater Creek is merely a dry sand bed. In two places, however, the stream has cut through the Tertiary deposits into the Cretaceous rocks below, and at these points springs issue, known as Buffalo and Agua Fria springs. (See p. 45.)

Palo Duro Creek (not to be confused with the stream of the same name farther south, in Palo Duro Canyon) rises in southern Sherman County and flows northeastward in a shallow valley on the level prairie. In this region the stream rarely contains water.

CANADIAN RIVER.

Canadian River flows eastward across the Panhandle just south of the center. It is the largest stream in this part of the Great Plains and has the largest drainage area of any stream in the district. It rises among the high peaks of the Rocky Mountains in northern New Mexico and flows southeastward as far as the vicinity of Tucumcari Mountain, New Mexico, where it turns to the northeast and continues in that general direction across Texas and into Oklahoma. In New Mexico it drains a large area and receives several tributaries of considerable size, but near the Texas line the drainage area decreases in width, and in its course across the Panhandle the stream has a relatively narrow valley, the distance between the heads of the short tributary creeks on opposite sides of the stream averaging not more than 35 miles.

For practically its entire course from northern New Mexico across Texas and Oklahoma into Indian Territory the Canadian is a wide sand-choked stream. The channel is filled with shifting quicksand and is noted for being the most treacherous stream of the plains. Part of the year the channel is dry or contains only a small amount of water in an otherwise dry sand bed, but frequently it is a raging torrent. Sudden and rapid rises are common but irregular. The channel may have been dry for weeks when, without warning, a wall of water several feet high may rush down the stream bed, carrying everything before it. The river may continue high, sometimes for days, sometimes for weeks, and then it will gradually subside and the channel again become dry. In this region the bed of the stream averages perhaps half a mile in width, although there are localities

ıere the distance from bank to bank is more than a mile, and in few places, where the river flows between high bluffs, the stream d is constricted until it is not more than 200 yards wide. The nks are in most places low and sandy, except where the stream ws through a canyon bordered by bluffs, as, for instance, near the outh of Trujillo Creek, not far from the New Mexico line, where e river flows for 10 miles or more between high bluffs of red shale pped with Alibates dolomite. Near the mouth of Amarillo Creek e same condition occurs, and in the eastern part of the region the ibates dolomite is again carried up along an anticline and forms nspicuous bluffs averaging 200 feet high for 20 miles or more. In ese localities the valley of the river is comparatively narrow.

The water of the Canadian is usually turbid, and, particularly in mes of freshet, red. The color is derived from the red-beds clays ver which it passes, and is so marked that in its upper course the tream is known as Red River.

In the western part of the Panhandle the Canadian receives about 0 tributary creeks, the greater part of which are relatively short, nly four being more than 20 miles in length. Of those which enter from the north the most important are Big Blue, Plum, Big Canyon, Saddlehorse, Fort, Ranch, Pitcher, John Ray, Lahay, Corral, Sand, India, Casino, Piscodo, Tascosa, Rica, Cheyenne, Rita Blanca, Moneto, Pedroza, Antelope, Minneosa, and Caballo. From the south the larger tributaries are Turkey, Alibates, Short, Molyneux, Coietas, Chicken, Bonita, Pedrosa, East Amarillo, West Amarillo, Horse, Tecovas, Sierra de la Cruz, Cottonwood, Parker, Alamosa, Skunk, Alamositas, Las Achias, and Trujillo creeks. Perhaps half of these streams flow all the year; some are always dry except after heavy rains, and others are intermittent. The water in the majority of them is derived from Tertiary springs near the heads of the creeks, and is consequently fresh. In a few creeks, however, particularly Big Canyon, Saddlehorse, and Alibates, in the eastern part of the region, the water, which comes largely from springs in the Permian red beds, contains gypsum and other salts in greater or less proportions, so that it is not suitable for irrigation or domestic uses.

RED RIVER.

A considerable part of Deaf Smith and Randall counties, in the southern part of the region, drains into Red River through Tierra Blanca and Palo Duro creeks. These streams, which rise as shallow prairie draws on the highest portion of the Llano Estacado in eastern New Mexico, pass into Texas, and for a distance of 25 miles in Deaf Smith County carry no water except after heavy rains. Near the center of this county the streams cut into Tertiary deposits and springs appear low down in the valleys. These springs increase in number

and size as far as the junction of the two creeks at Canyon, where each creek carries about 15 second-feet of water. From this point to the east line of Randall County Palo Duro Creek flows in a deep canyon. In this part of its course it receives the water from a number of short creeks fed largely by Tertiary springs. The largest of these are Timber, Sunday, and Canyon Cita creeks, which empty from the south and drain the southeast corner of Randall County.

DRAINAGE OF THE HIGH PLAINS.

A considerable portion of the High Plains region does not drain into any stream. This part constitutes the original level of the High Plains, "unscored by drainage, yet standing in relief," from which there is practically no run-off. The headwaters of the small creeks tributary to Canadian River and Palo Duro Canyon are working their way headward into this level plain and a few meandering shallow draws, such as those which form the upper courses of Coldwater, Perico, and Tierra Blanca creeks, traverse the plain in various directions; but by far the greater part has not yet been encroached on by stream channels.

The supply of rainfall on the greater part of the High Plains is collected in shallow saucer-shaped depressions known as "lakes" or as "playa lakes," which are scattered at irregular intervals on the plains. These depressions vary in size from the ordinary "buffalo wallow," a few feet across and a foot or two deep, to lakes several hundred rods in diameter, sunk 20 to 40 feet below the general surface level. In Deaf Smith County, for instance, there are a number of these depressions, each of which occupies an area of more than a square mile. In several instances, particularly in localities near the edge of the plains, the depressions are deep and bowl-shaped. Many of the lakes are perennial and afford an abundant supply of stock water throughout the year; others are ephemeral, being filled by rains and soon becoming dry; while still others contain water only rarely. These lakes occur on the plains with no regularity; in some localities there are none for miles, while in others there are scores in a single township.

Many of the larger depressions have drainage basins, some of which are several square miles in area. The traveler crossing the High Plains not infrequently encounters a shallow draw on the level surface along which after a heavy rain the water is carried to a near-by lake. Few of these small stream beds, however, exceed a mile or two in length and 10 feet in depth.

The influence of these lakes on the settlement of the country has been important, for on the High Plains the matter of water supply is vital. In the early history of the Panhandle, before wells had been sunk, these lakes constituted practically the only supply. Wagon trains in crossing the Llano Estacado came to camp beside lakes which

ways contained water, and many of the first "cow camps" were cated in similar positions. In a number of instances a town grew p at the site of the cow camp, and to-day some of the largest of the ›unty seats in the Panhandle, such as Amarillo, Hereford, Panhanle, Clarendon, and Claude, owe their location to the presence of lakes n the High Plains.

IRRIGATION.

NECESSITY FOR IRRIGATION.

The part of Texas to which this report relates is located in the emiarid belt of the Great Plains. At Amarillo the annual rainfall or twenty years has averaged 21.94 inches. At Albert, N. Mex., west of this region, the average annual precipitation for fourteen years was 16.32 inches. This amount. however, is very irregularly listributed, the greater part of it falling in a few violent rains. During certain seasons there is little or no rainfall, and occasional years of drought occur, during which the precipitation does not exceed 15 inches. The soil is extremely fertile and wherever water can be obtained is capable of producing abundant crops.

Farming has often been attempted on the High Plains. In former years the field crops like those raised farther east, such as wheat, cotton, corn, oats, and the ordinary garden vegetables, were planted in many parts of the Panhandle. Occasionally such a crop matured, but more often sufficient rainfall at critical periods was lacking and the result was failure. At present very few attempts are being made to raise ordinary farm crops, cultivation being restricted to such forage plants as milo maize, kaffir corn, and sorghum, which mature with a minimum of moisture. In seasons of average rainfall these forage plants produce practically as many bushels of grain per acre as do ordinary farm crops in more humid regions, and each year the acreage of such crops is increasing. There is a Government experiment station at Channing, in the western part of the Panhandle, where experiments have been conducted during the last few years with grains such as macaroni wheat and spelt, brought from semiarid regions in other parts of the world, notably from southern Russia, in the endeavor to obtain plants that would mature and produce staple crops in this part of the High Plains. It is very probable that within the next few years, as suitable crops are found and more intelligent methods of farming are introduced, the Panhandle will produce without irrigation many times the amount of grain raised at the present time. It is doubtful, however, if the ordinary field crops raised in the Eastern States will ever be successfully produced here.

It is obvious, however, that in a region with climatic conditions such as those just described irrigation would be a great aid to suc-

cessful farming and the ultimate development of the region. This fact has not escaped the attention of the inhabitants and in a number of localities in the Panhandle irrigation on a small scale has been attempted, the source of supply in most cases being a creek fed by Tertiary springs. Up to the present time, however, no large system of irrigation has been planned.

SOURCES OF WATER SUPPLY.

There are at present four sources of water supply for irrigation in the Panhandle of Texas, viz, streams, springs, storm waters, and wells. None of these, however, except the streams, has been used extensively.

Irrigation from streams.—In this region very few streams carry sufficient water for irrigation on a large scale. The Canadian is the only river which has its source in the Rocky Mountains, and, as has been stated, its flow is very irregular, being sometimes a rushing torrent and again for long periods almost or quite dry. There is no gaging station on the Canadian in Texas, but the following records, taken at Logan, N. Mex., a few miles west of the State line, indicate the extreme variability of the river.

Discharge measurements of Canadian River near Logan, N. Mex.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. feet.*	*Ft. per second.*	*Feet.*	*Sec.-ft.*
1904.						
June 29	W. G. Russell	245	64	0.87	0.55	56
August 10	do	388	1,400	5.32	4.50	7,446
October 2[a]	do		13,520	11.05	31.30	149,400
October 22	do	119	174	3.72	3.00	647
1905.						
October 10	E. Patterson	30	22	.61		14
November 20	do	43	43	1.70		73

[a] October 2, 1904, one of the most disastrous floods in the history of the river occurred, destroying most of the wagon and railroad bridges along the entire course of the stream. The normal discharge except in time of floods is probably less than 100 second-feet.

It appears that the water in the Canadian is sufficient, if all is utilized, to irrigate many thousands of acres, but unfortunately under present conditions it does not seem possible to make it available. In most cases the difficulties of storage would be great. Dam sites are rare on most of the streams of the Great Plains and so far as known none are available on the Canadian in the Panhandle of Texas. The channel is broad and shallow and filled with sand, in places, to considerable depths. For instance, at the point where the Fort Worth and Denver City Railroad crosses the river between Tascosa and Channing, in northeastern Oldham County, the sand was found to be 160 feet deep.[a] The scarcity of suitable building

[a] On the authority of the bridge foreman.

erials is a serious problem over a great part of the High Plains, in this region this difficulty does not exist, for there is at various lities an abundance of dolomite and sandstone, of which masonry s might be constructed. But even if it were possible to build rvoirs the river valleys contain few areas of any considerable size ıble of being irrigated. The flood plains are in most places nar-, or, if wide, are generally composed of sandy soil across which ould be difficult to carry water in ditches. All of these conditions to the conclusion that irrigation on a large scale can not be suc-fully practiced along the Canadian in the western part of the handle.

rigation along Palo Duro Canyon in eastern Randall County is feasible because the canyon is so narrow that there are no suffi-tly large areas suitable for irrigation. The supply of water in this von approximates 20 second-feet, an amount sufficient to irrigate nsiderable area if land were available.

or a number of years irrigation on a limited scale has been success-y practiced along some of the smaller streams in the region. In ost every instance the stream so utilized is fed by Tertiary springs. ng various tributaries of the Canadian in northern Potter County eral projects have been in successful operation for some time. At headquarters of the L. X. ranch, 25 miles northeast of Amarillo, water from Bonita Creek is utilized to irrigate 150 acres of alfalfa, on the same ranch, a few miles farther west, the water from her Creek is utilized in the same way. On Palo Duro and Tierra nca creeks in western Randall and eastern Deaf Smith counties re are several small irrigation plants. A number of other creeks he region carry sufficient water to irrigate considerable areas, and he country becomes more densely populated there is little doubt t year by year a greater percentage of this surplus water will be so ized.

rrigation from springs.—A considerable number of springs in this on can be utilized for irrigation purposes. In several instances s has been done, but in most of such cases there are several springs e together, the combined flow of which is taken. At best, how-r, irrigation from springs in the Panhandle must be confined to ited areas, for the amount of water flowing from a single spring is no case large.

t Buffalo Springs, near the Oklahoma line, in northwestern Dallam nty, irrigation has been in successful operation for more than ten rs. The water, which has its origin in the Dakota sandstone, issues number of vents along two branches of Coldwater Creek, and half ile below the junction of the two branches a ditch has been led off rrigate 150 acres of alfalfa and garden. The amount of water at s place is approximately 5 second-feet.

At Tascosa, the county seat of Oldham County, strong Tertiary springs furnish the water supply for the town, and at various times irrigation has been practiced. At the farm of J. M. Morris, half a mile east of Tascosa, where the water from a Tertiary spring is utilized to irrigate an orchard and garden, good results have been obtained. At the old X I T headquarters on Alamositas Creek several acres have been irrigated from a Tertiary spring, and on Rita Blanca and Minneosa creeks small irrigation plants have been established at various times.

There are in the region hundreds of Tertiary springs with flows of 1 second-foot or less which at present are not utilized. On many of the numerous tributaries of Canadian River there are scores of such springs. As settlement increases it may be confidently expected that those who come into the country will take advantage of these natural irrigation sites and that within the next decade irrigation from springs will be greatly developed.

Irrigation from storm waters.—As has been stated, much of the rainfall of the Panhandle occurs as dashing showers at irregular intervals, chiefly during the spring and summer months. After a shower the water on the High Plains accumulates in shallow sags, and the greater part eventually finds its way into the broad, shallow lakes which are scattered over the plains. Among the breaks it passes into the smaller streams which empty into Canadian River or Palo Duro Creek. In numerous places the sags on the plains or the dry channels among the breaks have been dammed, forming reservoirs known locally as "tanks," to hold stock water. In several instances a ditch has been led out of one of these artificial ponds to irrigate a few square rods of garden or orchard. During the last few years the number of such plants has increased, and while it is obvious that irrigation of this character can never be practiced on a large scale it is nevertheless possible for hundreds of families in the region to be provided by this means with home-grown vegetables and fruit.

Irrigation from wells.—In the discussion of artesian water in another part of this report the conclusion was reached that the prospects for an artesian supply over the greater part of the Panhandle of Texas were not good. On the other hand, ordinary wells, which are common in all parts of the region, furnish as a rule more water than is needed for stock and domestic use. In most of the wells on the plains the supply is practically inexhaustible with ordinary windmill pumping, and the surplus above what is used for the purposes named might well be utilized for irrigation. In many places the chief difficulty in the way of such utilization is the expense of lifting the water to the surface. In this region wind power is almost universally used for this purpose, and in localities where wells are shallow (as, for instance, along stream valleys or in the vicinity of Hereford,

in Deaf Smith County, where the water is not on an average more than 60 feet below the surface) it has been found profitable to use well water for irrigating small areas.

In the greater part of the Panhandle, however, the water is too deep to be available. As has been stated, the average depth of the wells on the High Plains is over 200 feet and in some localities the water is 400 to 500 feet below the surface. It is obvious that under such conditions little more can be done than to irrigate a garden or an orchard, and so far as observed this is all that has ever been attempted. Examples of this method of irrigation are not uncommon in many parts of the region, many ranchmen having a small garden irrigated from a deep well.

FUTURE OF IRRIGATION.

The local conditions being taken into account, there is little reason to suppose that there will ever be any extensive irrigation works constructed along the streams in this region. The supply of water is insufficient except in Canadian River and Palo Duro Creek, and on neither of these streams are the conditions such that large irrigation projects could be successfully carried out. Small streams, springs, artificial ponds, and wells supply water for limited irrigation—sufficient in many cases to raise vegetables and fruit for a family and even to irrigate several acres of field crops. But there is little to warrant the hope that change of climatic conditions will cause the water supply of the Panhandle to increase, and unless some means more efficient than the ordinary windmill be obtained to lift the water from deep wells, it is extremely improbable that extensive works can ever be installed. On the other hand, it is obvious that only a small part of the available water is now being utilized and it is possible that the future will witness in this region thousands of small pumping plants, each capable of supplying sufficient water to irrigate a small tract. By the utilization of spring waters now allowed to go to waste and of surplus water from wells it will be possible to secure home comforts otherwise unattainable.

WATER CONDITIONS BY COUNTIES.

GENERAL STATEMENT.

Of the eight counties under discussion the four lying farthest east—Sherman, Moore, Potter, and Randall—are each 30 miles square, while the four lying to the west, touching the New Mexico line, are 30 miles north and south and approximately 48 miles east and west. The usual system of public-land surveys, so common in the central and western parts of the United States, is not employed in Texas for the reason that when this State came into the Union by annexation it retained its own public lands. There are no regular

section, township, or range lines, but the land has been laid off into irregular blocks and subdivided into tracts containing either a square mile or a league. Some of the earlier surveys employed the Spanish vara, which equals 33.385 + inches; 1,897.7 + varas equal 1 mile. No accurate base maps of the region are available; that which forms the basis of Pl. III was compiled from a number of county maps.

SHERMAN COUNTY.

Topography.—Sherman County is situated in the northeastern part of the region and is bounded on the north by Oklahoma. Its surface is generally a level plain with a mean elevation of 4,000 feet, sloping gradually to the east. Beaver Creek has eroded a valley averaging half a mile wide and 100 feet deep for 5 miles through the northern part. Coldwater Creek flows eastward across the county north of the center in a meandering valley 50 feet deep and a quarter of a mile wide. In the southeast corner is the head of Palo Duro Creek, here only a shallow draw.

Geology.—The rocks of Sherman County are all of Tertiary and Quaternary age, this being the only county in the region in which pre-Tertiary rocks are not exposed on the surface. White cliffs of Tertiary clay outcrop here and there along the creeks, but throughout the greater part of the county few rocks are exposed, the surface being everywhere covered with a thick sod carpet of buffalo grass.

Water supply.—Beaver, Coldwater, and Palo Duro creeks are tributary to North Fork of Canadian River, but, except after local rains, rarely contain any water. Numbers of shallow "lakes" are scattered over the surface in nearly all parts of the county, into which is gathered the greater part of the rainfall, to remain until it evaporates or soaks into the ground. The surface is level, with few canyons where erosion has exposed the water table; consequently there are few springs. Well water is abundant in all parts of the county, and because of the absence of springs and running streams is depended on entirely for water supply. The depth of the wells varies considerably. At Stratford, the county seat, the court-house well found water at a depth of 230 feet, while from 15 to 18 miles south of the town a number of wells vary from 300 to 400 feet in depth. North of Stratford the wells average 250 feet and a few miles farther east from 175 to 225 feet in depth. A few wells located in the valley of some creek, such as Beaver or Coldwater, are not more than 60 feet deep, but on the High Plains most wells are more than 150 feet in depth. The average depth of 28 wells in different parts of the county is 197 feet.

DALLAM COUNTY.

Topography.—Dallam County is located in the northwest corner of exas, and is bounded on the north by Oklahoma and on the west by ew Mexico. The surface is a level plain sloping eastward from an evation of 4,800 feet near the northwest corner, the highest eleva- on in the Panhandle, to approximately 4,100 feet in the northeast rner, an average slope of 12 feet to the mile. Coldwater Creek in ie north and Perico and Carriso creeks in the southwest have cut iallow valleys into the level upland plain.

Geology.—The greater part of the surface rocks of Dallam County re of Tertiary origin, and where exposed along the bluffs of shallow ream valleys exhibit the ordinary white clay cliffs, with a few ledges sand, gravel, and pebbles. In the southwest part of the county iere is a sandy region with low irregular dunes. Along some of the eek beds in the northern and western parts, where erosion has moved the Tertiary deposits, Cretaceous rocks, consisting of beds of ft yellow to brown sandstone interbedded with shales, are exposed ere and there. These exposures occur on Coldwater Creek at Buffalo id Agua Fria springs, at a point near the New Mexico line in the xtreme northwest, and near Texline on both the north and south ranches of Perico Creek.

Water supply.—Across the county from northwest to southeast flow iree shallow creeks—Coldwater, Perico, and Carriso. Coldwater reek, which is locally known as Rabbit Ear Creek from the fact that rises in the Rabbit Ear Mountains, flows in a meandering valley cross the northern part of the county. It carries water only below he points where Cretaceous springs occur. Perico and Carriso creeks, hich rise among volcanic peaks on the High Plains of northeastern lew Mexico, flow southeastward across Dallam County and unite iear Dalhart, forming Rita Blanca Creek, a tributary of the Canadian. Both Perico and Carriso creeks are shallow sand draws and rarely ontain water. The greater part of the rainfall soaks into the ground r flows into prairie lakes, where it evaporates.

The only springs of importance in Dallam County are Buffalo and Agua Fria (see p. 45), both of which are located on Coldwater Creek. They issue from Cretaceous rocks exposed near the creek bed, and fter flowing for a few miles disappear beneath the sands. The flow rom Buffalo Springs approximates 5 second-feet; that from Agua ria Springs is not nearly so great, perhaps less than 1 second-foot.

Wells are common in all parts of Dallam County. By far the reater part of them have been drilled for stock water by the Capitol and and Cattle Company, the owners of the noted X I T ranch, hich formerly contained 3,000,000 acres of land located in ten of the counties of northwestern Texas. In the northwestern part of Dallam

County, where Cretaceous rocks approach the surface and the superficial Tertiary deposits are thin, water is found at comparatively shallow depths. Some wells here encounter a supply ample for stock and domestic use at 10 to 25 feet, but the greater number go down for 75 to 100 feet. Farther southeast, where the Tertiary deposits are thicker, the depth to water increases, and in the region north of Dalhart in the south-central part of the county much of the water is found at depths ranging from 250 to 400 feet. In one area 15 miles square in this vicinity the average depth of the wells is 400 feet. The average depth of 27 wells in Dallam County is 212 feet.

HARTLEY COUNTY.

Topography.—Hartley County lies south of Dallam, being the second from the north in the western tier of counties in the Panhandle. The surface for the greater part slopes gradually to the south and east. All of the county is typical of the High Plains, except certain areas in the southern part, which lie in the breaks along the heads of various creeks flowing southward into Canadian River. In this region the heads of these streams have cut into the flat upland, forming numerous shallow valleys. The valley of Rita Blanca Creek, which averages 75 feet in depth and a mile in width, extends from north to south across the eastern part of the county.

Geology.—The greater part of the surface rocks in Hartley County are of Tertiary age. Along the upper courses of some of the creeks which rise in the High Plains in the southern part and flow southward into the Canadian are white cliffs composed of Tertiary clay. A considerable part of the western half of the county contains low sand dunes derived from Tertiary sand. Triassic red beds are exposed along the streams in the southern part of the county where Tertiary deposits have been eroded.

Water supply.—Rita Blanca Creek is the largest stream in Hartley County. It is a typical High Plains stream and is formed by the junction of Perico and Carriso creeks, which unite near Dalhart at the north line of the county. Neither of these creeks carries water except after heavy rains, and Rita Blanca throughout the greater part of its course southward across Hartley County is merely a dry sand bed. At a point about 15 miles above the mouth of the creek the stream cuts through the Tertiary rocks and exposes the underlying red beds, which outcrop along the creek from this point to the river. Springs, which issue at the line of unconformity, furnish sufficient water to produce a running stream below this point for the greater part of the year. Punta de Agua Creek, which flows eastward and empties into Rita Blanca Creek in the southern part of the county, is ordinarily a dry sand bed. Its chief tributary, Middle-water Creek, carries little or no water except after heavy rains.

Besides Rita Blanca and its tributaries some of the streams which rise in Hartley County and flow southward into Oldham County before reaching the Canadian are the following: Tascosa, Rica, Cheyenne, Moneto, Pedroza, Antelope, Minneosa, and Caballo. On the High Plains in the northern and central parts of the county there is no run-off, and the water derived from rainfall either soaks immediately into the ground or passes into shallow lakes, whence it is slowly evaporated.

Springs, mostly of Tertiary origin, are found along certain creeks in the southern part of Hartley County. Some of these springs issue at the red beds—Tertiary contact, and some from a sandy stratum in the Tertiary. Much of the water that supplies Tascosa, Cheyenne, Rita Blanca, Antelope, and Minneosa creeks comes from Tertiary springs in southern Hartley County. In general these springs are not particularly strong, averaging perhaps not more than one-tenth to one-fourth second-foot, but the water derived from them is sufficient for stock, so that in this vicinity wells are not as common as on the High Plains farther north.

In the northern and northeastern parts of Hartley County the depth to water varies from 250 to 400 feet. Near Hartley, east of the center of the county, the wells are 350 to 375 feet deep, and at Channing, the county seat, their average depth is 300 feet. In the western part of the county, in what is known as the Middlewater district, water is found at depths varying from 160 to 200 feet. Among the breaks in the southern part of the county the wells vary from 10 to 150 feet in depth. At Willow Springs ranch, 12 miles west of Channing, an artesian well is reported. The records of 76 wells in all parts of Hartley County show an average depth of 240 feet, a greater average depth than in any other county in this part of the Panhandle.

MOORE COUNTY.

Topography.—Moore County is situated south of Sherman and east of Hartley. It is the second county south of Oklahoma and the second east of New Mexico. Its greater part lies on the High Plains, at an elevation varying from about 4,000 feet in the northwest corner to a little less than 3,000 feet along Canadian River in the southeastern part. The latter elevation is the lowest in the region to which this report relates. In the southern and southeastern parts of the county the topography is rough, the High Plains being dissected by several short creeks tributary to the Canadian, which crosses the extreme southeast corner of the county. Several of these creeks, particularly Big Blue and its tributaries, have carved narrow, steep-sided canyons in places as much as 200 feet deep.

Geology.—Throughout the greater part of Moore County only Tertiary rocks are exposed on the surface. White Tertiary cliffs occur

in the breaks near the heads of various creeks, and in certain localities low sand dunes are found. Permian red beds outcrop along the Canadian and on the lower course of Big Blue Creek, both the Greer and Quartermaster formations being exposed. A prominent member of the Quartermaster formation is the Alibates dolomite lentil, which forms the escarpment of the canyon of Big Blue Creek. The Alibates is also conspicuously exposed on the bluffs along the river.

Water supply.—The drainage of Moore County flows southeastward into the Canadian. This river, which flows for 3 miles across the southeastern part of the county, is here contained between high bluffs of red clay capped by the Alibates dolomite. Big Blue Creek, which drains a considerable area in the central and southeastern parts of the county, is formed by two branches, both of which begin as flat draws on the High Plains. In the course of their development they have cut through the Tertiary deposits, exposing the water table, whence springs issue. From this point to its mouth, just across the line in Hutchinson County, Big Blue Creek is a running stream. Farther west are Corral, Sand, India, and Casino creeks, which rise in Moore County and pass into Potter County before emptying into the Canadian. All these streams are fed by Tertiary springs and contain water for parts of their courses only. A considerable portion of central and northern Moore County has no drainage except into lakes on the High Plains.

Most of the springs in Moore County occur in the southern and southeastern parts near the heads of the creeks just mentioned, particularly Big Blue Creek. As a rule, they issue at the Tertiary and red beds contact, but a few start at a higher horizon. Their water is almost uniformly fresh and pure. The flow from any one spring is in few cases large, but the aggregate from the hundreds that occur in the region is considerable, so that not many wells are necessary to furnish stock water. Springs in the red beds occur along the Canadian and the creek valleys. The water from some of these springs is fresh, but in most cases it contains a sufficient amount of mineral salts, chiefly gypsum, to make it unpalatable and even to render it unfit for domestic use.

Few of the wells which have been bored on the High Plains in the central, northern, and western parts of Moore County fail to obtain an abundant supply of water. At Dumas, the county seat, wells are 260 feet deep. East of Dumas they are from 160 to 200 feet deep, while in the western part of the county the average is 240 to 300 feet. Near the northern line the depths vary from 150 to 225 feet, and along Blue Creek and in the breaks in the southern part of the county they average from 10 to 100 feet. There is an artesian well on Big Blue Creek in the eastern part of the county, the water of which probably comes from the Triassic formations below the Tertiary. In the red-

beds area in the valley of the Canadian, where but few wells have been sunk, the water is generally poor. The average depth of 36 wells in Moore County is 161 feet.

POTTER COUNTY.

Topography.—Potter County is situated west of the center of the Panhandle, in the third tier of counties from the Oklahoma line, and the second tier east of New Mexico. Its extreme southern part only is on the High Plains; the Canadian flows eastward across the northern part. The greater part of the county lies in the breaks of the Canadian, and the topography is consequently rough, being characterized by rounded hills and knolls and in places by rather narrow, steep-sided canyons and intervening slopes. Sand dunes occur on Chicken Creek and neighboring streams in the northern part of the county and on the slope north of Canadian River.

Geology.—Both Tertiary rocks and red beds are well exposed in Potter County. On the High Plains near Amarillo, in the southern part of the county, the rocks are the ordinary High Plains Tertiary. Near the edge of the Llano Estacado there are conspicuous cliffs of white clay, while farther north in the breaks, particularly along the divides between the small creeks, are rounded knolls and small ridges, many of them covered with smooth waterworn pebbles, weathered out from the lower members of the Tertiary. Along the river and most of the tributary creeks both Permian and Triassic red beds occur, all the members of both series from the Greer gypsum to the middle sandstone of the Trujillo formation being well exposed. Prominent cliffs of red shale occur in various localities, capped here by the Alibates dolomite and there by the lower sandstone of the Trujillo.

Water supply.—The channel of Canadian River, the largest stream in Potter County, averages half a mile in width. The banks are for the most part low and sandy, although in certain localities—as for instance, near the mouths of Bonita and Amarillo creeks—steep bluffs occur, capped usually with Alibates dolomite. As has been stated, the channel is usually dry, but the river is subject to sudden and rapid rises, in which great quantities of water pass down the stream in a few hours. The chief tributary creeks which enter the Canadian from the north in Potter County are Plum, Big Canyon, Saddlehorse, Fort, Ranch, Pitcher, John Ray, Lahay, Corral, Sand, India, and Casino, while those from the south are Turkey, Alibates, Short, Molyneux, Coietas, Chicken, Bonita, Pedrosa, East Amarillo, West Amarillo, Horse, Tecovas, and Sierra de la Cruz. Practically all of these creeks rise as shallow sand draws on the High Plains and flow toward the river, finally cutting through the Tertiary deposits and into the red beds before reaching the main stream. Most of

them have water in their lower courses only; a few are dry except after heavy rains; while others, notably Bonita, Ranch, and Pitcher creeks, have sufficient water all the year for a small amount of irrigation. On the High Plains in the southern part of the county there are a number of lakes into which the surplus water from rainfall collects and remains until it evaporates.

Springs occur in Potter County chiefly at the usual horizon, viz, the line of unconformity at the top of the red beds. Water from the Tertiary deposits of the High Plains both north and south of the river comes to the surface at this level and issues as springs which supply the creeks mentioned above. Few individual springs afford more than one-fourth or one-half second-foot of water, but the aggregate from the great number of springs is considerable, as illustrated by such streams as Bonita, Chicken, Ranch, and Pitcher creeks, each of which flows several second-feet. Springs also occur in the red beds in this county. As a rule the water from those in the Triassic formations is good, but much of that from the Permian beds contains appreciable amounts of mineral salts and is unfit for domestic use.

Very few wells have been put down in Potter County except on the High Plains in the southern part. In the breaks along the river an ample supply of water for both stock and domestic uses and in many places a surplus for irrigation is furnished by springs. At Amarillo, the county seat, the wells average 240 feet in depth. Farther east, in the direction of Panhandle, their depth increases in some cases to 300 or 350 feet. An average of 23 records obtained in this county is 260 feet, but this average is misleading, for in the breaks near the river, where wells are not common, those that have been put down are relatively shallow, not averaging more than 50 feet, so that for the entire county the average depth is perhaps not more than 150 feet.

OLDHAM COUNTY.

Topography.—Oldham County is located on the west line of the State, being the third county south of Oklahoma. Its topography is very similar to that of Potter County. The southern part lies on the High Plains, and Canadian River flows eastward near the northern line. Thus the greater part of Oldham County lies on the slope south of the river, and into this slope a number of short creeks, flowing northward, have cut minor valleys, producing a rugged topography. North of the Canadian also the country is broken. In the western part of the county the Canadian flows between cliffs of red shale 150 feet high, capped by the Alibates dolomite, and in the same region a number of creeks have cut canyons through this formation.

Geology.—The rocks of Oldham County are all red beds or Tertiary deposits. Along the river near the mouth of Trujillo Creek the

Quartermaster formation is exposed and with it the Saddlehorse gypsum and Alibates dolomite lentils, the latter forming the cap of conspicuous bluffs for miles along the various streams. Most of the red beds, however, are of Triassic age, both the Tecovas and the Trujillo formations being well exposed along the river and in the valleys of the various creeks, extending in places as far back as the edge of the High Plains. Along the creeks red clays and gray and yellow sandstones are conspicuous. Near the mouth of Trujillo Creek the variegated shales of the Tecovas formation are represented by a ledge of soft yellow to red sandstone containing fossil wood. The High Plains in the southern part of the county are composed of Tertiary rocks, as are also the divides between many of the creeks. The northern edge of the Llano Estacado in this county is in most places a cliff 50 to 200 feet high, composed of white clay. Along the slopes and on the smaller divides smooth waterworn pebbles cover the ground and gravel points are common.

Water supply.—Oldham is the best watered county in the western part of the Panhandle. Canadian River, which flows eastward across its northern part, is in most places a broad, shallow, sand-choked stream, often dry, but subject to rapid rises. Along a part of its course in Oldham County the river is narrow and is contained between bluffs 100 to 140 feet high. In general, however, its valley is from 1 mile to 2 miles wide. Numerous tributary creeks which rise near the edge of the High Plains enter from both north and south. Those from the north are Piscodo, Tascosa, Rica, Cheyenne, Rita Blanca, Moneto, Pedroza, Antelope, Minneosa, and Caballo. Of these Rita Blanca, the most important stream, is formed by the junction of Carriso and Perico creeks in southern Dallam County and flows entirely across Hartley County before entering Oldham. Practically all the creeks mentioned rise in Hartley County and are fed by Tertiary springs, so that in their course in Oldham County they are running streams for at least part of the year. Cottonwood, Parker, Alamosa, Skunk, Alamositas, Las Achias, and Trujillo creeks enter Canadian River on the south. Trujillo Creek, which is the largest, rises at the base of the High Plains in New Mexico and flows northeastward, receiving as tributaries Mujeres and Agua Piedra creeks before joining the river. Alamosa Creek is also a large stream and drains a considerable area. All of these streams are spring fed, but in most of them the water sinks into the sand before reaching the river.

Springs occur along all the streams in Oldham County, and particularly in the region south of the river hundreds issue at the Tertiary and red beds contact or from sandy beds in the Tertiary deposits. A notable example of a Tertiary spring is the one near Alamositas Creek at the old X I T ranch headquarters, which flows half a second-foot. Another valuable spring on Skunk Arroyo, a few miles east of

the one on Alamositas Creek, flows more than 1 second-foot. Strong Tertiary springs occur on Las Achias, Trujillo, Caballo, Minneosa, and Alamosa creeks.

Springs from the red beds are common. On Sierra de la Cruz, Parker, and Alamosa creeks the water issues in places from beneath the various sandstone ledges of the Trujillo formation and in places from joints in the red clay. On Las Achias Creek a number of strong springs issue near the Alibates dolomite. All the Tertiary springs and the majority of those from the red beds in Oldham County supply fresh water. The water from a few springs which issue in the Permian red beds, however, contains gypsum and other mineral salts.

Wells are not common in Oldham County, except on the High Plains near the southern line, for the reason that springs are abundant in most localities and furnish an ample supply of stock water. North of the river there are a few wells which average 100 to 150 feet in depth. On the Llano Estacado in the southern part the average depth is 200 feet, varying from 160 to 245 feet. The average depth of 12 wells in Oldham County is 160 feet.

DEAF SMITH COUNTY.

Topography.—Deaf Smith County, the southwesternmost county in the region, is bounded on the west by New Mexico and is the fourth county south of Oklahoma. All of it is situated on the Llano Estacado except the extreme northwest corner, which lies in the valley of Trujillo Creek at the foot of the plains. The shallow channels of Palo Duro and Tierra Blanca creeks each follow a meandering course eastward across the county. At the eastern line these streams have cut canyons averaging 50 feet in depth and a quarter of a mile in width.

Geology.—The rocks of Deaf Smith County are chiefly of Tertiary age, but, as is usual on the High Plains, very few outcrops occur. In the northwestern part of the county, at the edge of the Llano Estacado, there are cliffs 100 to 150 feet high composed of white Tertiary clay, and at the foot of the plains in the same locality ordinary pebbles are found. Red beds of Triassic age occur at the foot of the plains along the various small tributaries of Trujillo Creek.

Water supply.—Streams are rare in most parts of Deaf Smith County. A few small creeks, all of which flow northward into Trujillo Creek, rise at the foot of the High Plains in the northwestern part. On the Llano Estacado Palo Duro and Tierra Blanca creeks flow entirely across the county from west to east. Both of these streams have their origin in New Mexico as shallow draws on the level plains and extend for more than 30 miles before carrying any water in their channels. About 15 miles from the eastern line of the county both streams have cut down to the water table and springs begin to

ppear along the creek beds, increasing in both number and volume ntil at the point where they leave the county each creek carries pproximately 5 second-feet of water. Most of the rainfall flows into he numerous lakes, which include some of the largest in the Pan-andle.

A few springs issue from the red beds and Tertiary contact at the oot of the plains in the northwestern part of the county, but none of hem are of any great importance. Hundreds of springs issue along he beds of Palo Duro and Tierra Blanca creeks in the eastern part. The water of these evidently does not issue as usual from the uncon-formity at the base of the Tertiary deposits, but from sand and gravel strata in the Tertiary. Few of the springs are strong, but the aggre-gate flow from the great number that occur is considerable.

Wells are abundant in Deaf Smith County. At the foot of the plains in the northwestern part there are a few wells averaging 80 feet in depth, which obtain water in the red beds; this water is usually not good. On the plains the depth varies considerably in different localities. In the western part 13 wells average 254 feet, varying from 155 to 375 feet. In the northeastern part wells vary from 100 to 150 feet in depth. Near Hereford, the county seat, in the south-eastern part, water is shallower than on any part of the High Plains south of the Canadian in this region, the average depth being 60 feet. In the town of Hereford there are nearly 200 windmills. The aver-age depth of 21 wells in the eastern part of the county is 71 feet, while southwest of Hereford the depth to water is in places 300 feet or more. The average depth of 120 wells in all parts of Deaf Smith County is 94 feet, being the lowest of all the counties in this part of the Pan-handle.

RANDALL COUNTY.

Topography.—Randall is the southeasternmost county in the region to which this report relates. The surface is a level plain trenched in its eastern part by the deep gorge of Palo Duro Canyon. The canyon proper, which begins near Canyon, not far from the center of the county, is formed by Palo Duro and Tierra Blanca creeks, both of which, in the western part of the county, flow in valleys averaging 100 feet in depth and half a mile in width. From the junction of these two streams the canyon deepens steadily until at the eastern line of the county it is 800 feet deep. Throughout a considerable part of its course this canyon is not more than a mile wide, with steep, in many places, precipitous sides. Several smaller streams which enter from the south, notably Sunday, Timber, and Canyon Cita creeks, have cut short canyons which at their mouths are as deep as the main canyon.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE POTOMAC RIVER BASIN

GRAPHIC HISTORY—RAINFALL AND STREAM FLOW—POLLUTION, TYPHOID FEVER, AND CHARACTER OF WATER—RELATION OF SOILS AND FOREST COVER TO QUALITY AND QUANTITY OF SURFACE WATER—EFFECT OF INDUSTRIAL WASTES ON FISHES

BY

HORATIO N. PARKER, BAILEY WILLIS, R. H. BOLSTER
W. W. ASHE, AND M. C. MARSH

WASHINGTON

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1907

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THE POTOMAC RIVER BASIN.

By HORATIO N. PARKER, BAILEY WILLIS, R. H. BOLSTER, W. W. ASHE, and M. C. MARSH.

INTRODUCTION.

SCOPE OF THE PAPER.

Hardly a river basin in the country is of more importance from the point of view of the utilization of water resources than that of the Potomac. The water power developed in this area drives the wheels of many mills, and the waters of the streams are used in the processes of diverse industries. The beauty of the streams and the supply of fish have made a large portion of the basin a recreation ground for thousands of people, while the Potomac itself furnishes drinking water for the National Capital. In order to obtain definite information on the character of the water supply an extensive investigation was undertaken jointly by the Geological Survey, the Bureau of Forestry, and the Bureau of Fisheries. The result of this work is the present paper, in which are described all the conditions that affect the economic utilization of the water resources. The scope of the paper is best shown by enumerating the principal features of the investigation, which are as follows:

1. A study of the geographic history of the basin.

2. The determination of the amount of water flowing in the principal streams, a compilation of all data relating to the quantity of water, and a study of the distribution of the rainfall.

3. A complete reconnaissance of the drainage area with respect to sources of pollution, a study of the prevalence of typhoid fever in the District of Columbia and at other points, and an investigation of the quality of the surface water as shown by field assays and sanitary and mineral analyses of water taken at many points.

4. A study by the Bureau of Forestry of the effect of the soils and forest cover on the turbidity of the water and the flow of the streams, and the preparation of a map showing the forest conditions.

5. A study by the Bureau of Fisheries of the effect of industrial wastes on fishes.

ACKNOWLEDGMENTS.

The lively interest shown by many citizens of the Potomac basin in this report and the help they have given in its preparation are much appreciated. Especial recognition is due to W. D. Bryon & Sons, the United States Leather Company, J. R. Cover & Sons, the Hambleton Leather Company, the West Virginia Pulp and Paper Company, the Potomac Pulp Company, the Blue Ridge Knitting Company, the Washington Gas Light Company, and the Clapp Ammonia Company for furnishing samples of the effluents from their factories. This cooperation on their part has added materially to our knowledge of the effect of industrial wastes on fish life.

Acknowledgment should be made to the United States Weather Bureau for rainfall data; to the Chief of Engineers of the United States Army for profiles and elevations along certain portions of the river, and to the Maryland Geological Survey for the maintenance of the gages on Monocacy River and Antietam Creek.

HISTORICAL SKETCH OF THE POTOMAC BASIN.

By Horatio N. Parker.

The Potomac became of moment in English annals with the settlement of Jamestown, Va. Capt. John Smith discovered the river (Patawomek, as he spelled it) June 16, 1608, and sailed upstream about 30 miles to a point where, after having met with a hostile reception from the Indians, he landed on the Virginia shore. From this place, probably Nomini Bay, he continued up the river, touching at various points, until he had passed the present site of Washington, "having gone up as high as they could in a boat." Here they were met by savages in canoes loaded with the flesh of deer, bears, and other animals, of which they obtained a portion. On their return journey they met with many adventures, but reached Jamestown in safety. In early colonial times the name Potomac was applied to the river from its mouth to its junction with the Shenandoah at Harpers Ferry. The portion of the river from that point to its source at the headwaters of North Branch was called the Cohongoruton, a name said to be a corruption of the Indian Kohonk-on-roo-ta, or "wild goose stream," from the great number of wild geese that inhabited it, the "ko-honk! ko-honk!" of the bird suggesting the term.

Lord Fairfax in his land grants on this part of the watercourse designated it Potomac, by which means it gradually lost its ancient name. Shenandoah River was first called Gerando, then Sherandoah, and finally Shenandoah. For a long time after the settlement of Jamestown the colonists, terrified by the gloomy forests of the interior, clung to the coast; but in 1716 Governor Spottswood led an expedition to

the Blue Ridge and reached its summit, probably near Swift Run Gap. He descended into the valley, crossed the river, which he named Euphrates, and took possession of the country in the name of the King of England. There were no direct results from the expedition, but it had the good effect of dispelling the mystical terror with which the colonists had invested the region.

Prior to its occupation by the settlers the valley of Virginia was a hunting ground for various Indian tribes, who burned the grass every fall before going into winter quarters in order to keep down the forests. Consequently the only timber was along the streams and well back in the mountains. The forests that now exist have sprung up since those times. The trails followed by the colonists through the mountains were established by the buffaloes and other large game and were well worn by the Indians. The valley, as has been said, was a hunting ground rather than a permanent abode of the aborigines. Hence the few villages in it were of a temporary nature and had a fitful existence. The game consisted of buffalo, elk, deer, bear, panther, and wild cats, besides beavers, wolves, foxes, and other animals. The Indians welcomed the Pennsylvania colonists because of the trust they had in William Penn, but they showed great hostility toward the settlers from tide water, whom they called "The Long Knives," and whom they hated. In 1753 emissaries from west of the Alleghenies came among the valley Indians and invited them to cross the mountains, which they did in 1754. Their sudden exodus caused much uneasiness among the Virginia colonists, who feared that the action foreboded impending hostilities. This proved true enough, for it was probably French influence that coaxed the Indians away, and after Braddock's defeat they terrorized the valleys of South Branch and the Shenandoah, committing many outrages, and not being driven back until the close of the French and Indian war.

The upper and lower portions of the valley of Virginia were settled at about the same time. The colonists of the tide-water region made their way up the lowland rivers and finally passed over the mountains into the valley, and at the same time, or a few years before, the region toward the Potomac was settled by Scotch-Irish and Germans from Pennsylvania. The Scotch-Irish were the pioneers and established homesteads along Opequon Creek from the Potomac to what is now Winchester. The Germans followed. Joist Hite, in 1732, obtained a grant of 40,000 acres and with 16 families moved from Pennsylvania, cutting the road from York, crossing the Cohongoruton 2 miles above Harpers Ferry, and settling on Opequon Creek 5 miles south of Winchester. His followers built Strasburg and other towns along Massanutten Mountain. In 1733 Jacob Stover took a grant for 5,000 acres of land on South Fork of the Shenandoah, and in 1734 settlers from Monocacy, Md., located on North Fork of the Shenandoah, 12 miles

south of Woodstock. Two cabins, erected in 1738 near Shawnee Springs, were the beginning of the town of Winchester, long a frontier post of the colony in that quarter. John Lewis brought over from Ireland and Scotland 100 families and settled near what is now Staunton, Augusta County. Conococheague Creek was settled at Greencastle, Pa., in 1734, the place being first known as the Conococheague Settlements. In 1734 Richard Morgan obtained a tract of land near Shepherdstown, the oldest town in West Virginia. Romney, W. Va., was laid out by Lord Fairfax in 1742 and is the second oldest town in the State. In 1748 Robert Harper, an English millwright, came to Harpers Ferry. Benjamin Allen, Riley Moore, and William White built homes on the Monocacy prior to 1734, and in 1735 the Schleys, with about 100 families from Germany, Switzerland, and France, established themselves on the Monocacy, the first house in Frederick being erected by Thomas Schley in 1735. By 1748 the German immigrants had taken possession of many valuable tracts along Monocacy River and Catoctin Creek. At an early period many immigrants became occupants of the Cacapon and Lost River valleys and numerous settlements were made on Back and Cedar creeks. In 1741 Col. Thomas Cresap, with his own and several other families, located at "Shewaneese" Oldtown, on North Branch of the Potomac.

The first settlers on the Wappatomaka, as South Branch of the Potomac was called, located in 1734 or 1735. They failed to secure title to their lands, and so became involved in a dispute with Lord Fairfax, who, they felt, dealt harshly with them. There is a tradition that Lord Fairfax became interested in his Virginia venture through meeting John Howard, who, with his son, is said to have explored the valley of Virginia prior to its settlement and to have discovered the valley of South Branch, crossed the Allegheny Mountains, and gone down Ohio and Mississippi rivers to New Orleans, where they were arrested as suspicious characters and sent to Paris; thence, no cause being found for holding them, they went to London, where the meeting with Lord Fairfax is said to have occurred. Lord Fairfax came to Virginia in 1742 and opened an office in Fairfax County for granting land warrants. A few years later he moved to what he called Greenway Court, 12 or 14 miles southeast of Winchester, where he kept his office until he died in 1781. His surveyors decided that North Branch was the main stream of the Potomac and located the "Fairfax Stone" at its head October 17, 1746. This action was greatly to his advantage, for had South Branch been chosen as the "first fountain" the Fairfax holdings would have been much reduced. Later the States of Virginia and Maryland became involved in a dispute as to the location of the boundary line between them, and though the question has never been settled Virginia has been able to maintain the North Branch as the boundary, basing her claim on the location of the "Fairfax Stone."

In 1725 John Van Metre, a trader from Hudson River, traversed the lower Shenandoah, upper Potomac, and South Branch valleys, and at Hanging Rocks witnessed a bloody battle between two parties of Indians. He returned home much impressed with the richness of the South Branch region and advised his sons to move there, which they subsequently did. The earliest settlers found a natural clearing in the woods at Oldfields and built a fort there, which was the scene of many fights with the savages.

Lands on Patterson Creek began to attract the pioneers a little before Fort Cumberland was completed in the winter of 1754–55. In 1728 there was an Indian town known as Caiuc-tu-cuc on the ground between Wills Creek, or, as it was then known, Caiuc-tu-cuc Creek, and North Branch; it was located for the most part upon the site of the west side of what is now Cumberland. The Indian village was abandoned and in its place a settlement of whites slowly grew up. The last Indian to remain and have authority was known as Will, and the town for a long time was known as Will's Town, the creek as Will's Creek, and the mountain where he had his home as Will's Mountain. His rights in the country appear to have been recognized, for the early settlers always made him a present when they took up land. The first comer to Cumberland of whom there is record was an Englishman named Evitt, who led the life of a recluse in his cabin on top of Evitts Mountain, where he died before 1749.

Georges Creek took its name from an Indian, George, who had his hunting lodge on the present site of Lonaconing. He was a favorite of and lived with Col. Thomas Cresap, of Oldtown, who had employed his father, Nemacolin, to mark out the road from Cumberland to Brownsville, on the Monongahela. General Braddock followed the path and the national road varies but little from it. This testifies to the excellent manner in which the Indian did his work.

Cumberland was long the outpost of civilization in the Potomac Valley. The last refuge of the Indians was on Savage Mountain; hence its name. The first settlers on Georges Creek came from New Jersey and Virginia. Prior to 1830 there were not more than 30 houses in Georges Creek valley. North Branch above Westernport seems to have been well known at an early date. Washington, on his return from the trip to Ohio in 1784, crossed the stream and mentions in his journal for September 26 that he was told by Joseph Logston, who had hunted along the river, that there was no fall in it, and that from Fort Cumberland to the mouth of Savage River the water was frequently made use of in its natural condition for canoes, and that from thence upward it was rapid only in places, with loose rocks which could be easily removed.

September 27 Washington crossed Stony River, which he speaks of as appearing larger than North Branch. On his return to Mount Vernon he made a map of the country he had visited, on which was

shown North Branch with the tributaries Difficult Creek, Stony River, Abrams Creek, New Creek, Georges Creek, Savage River, and the head of Patterson Creek. A map by Joseph Shriver, published in 1824, shows North Branch from Westernport to its source, the only town above Westernport being Paddytown, now Keyser, W. Va.

Coal seems to have been known to the earliest settlers. In 1804 it was discovered near the present site of Frostburg. In 1810 a tremendous freshet stripped the earth from the banks of Guinea Run, displaying the coal on what is known as the Barton property. People came from miles around to see "the mountain of coal." For some time is was mined with mattocks and the ore was hauled to Winchester and Romney for blacksmithing purposes. In 1814 or 1815, while the national road was being made, coal was found at Eckhart Mines and was hauled in wagons to Cumberland and Baltimore. Three or four bateaux arrived at Washington April 20, 1826, laden with coal from the rich mines at Cumberland. Up to 1842 merchants, laborers, and others engaged in various pursuits in the summer and worked in the mines or coal banks, as they were called, in the winter, some as teamsters, some as boat builders, and some as miners. The coal was hauled to the river bank and piled there in large quantities. In the spring freshets the boats, which hauled from 1,000 to 1,500 bushels, were sent down the river to the purchasers. The flatboats were not returned, but occasionally a keel boat laden with supplies was laboriously poled back. From 50 to 60 boats, carrying an aggregate of 75,000 bushels of coal, comprised the total shipment each year previous to the completion of the Baltimore and Ohio Railroad in 1842. As the coal business was conducted up to that time, it was hazardous to capital and destructive to the lives of those engaged in carrying it on, many boats being wrecked on the rocks in the river. Hence few mines were worked, the chief being the old Eckhart mine, 9 miles west of Cumberland. The Georges Creek Coal and Iron Company was the first to develop mines west of Frostburg. It began excavations for its iron furnace in 1836. Coal was first shipped on the Chesapeake and Ohio Canal in 1850. The coal fields of North Branch above Piedmont were described by Prof. W. B. Rogers in 1839 in his report on the geology of Virginia.

The orderly development of the Potomac Valley proceeded until the outbreak of the civil war, when the arts of peace were suspended and this battle ground of the Indian became that of the white man. The great battles of Antietam and Gettysburg were fought within the valley's borders, as were a host of other no less bravely contested engagements. For four years the work of destruction went on, but with the advent of peace in due time came prosperity, which has continued, until to-day the growth of the industries and population in the valley is healthy and vigorous.

GEOGRAPHIC HISTORY OF POTOMAC RIVER.

By BAILEY WILLIS.

GENERAL DESCRIPTION OF BASIN.

The Potomac, rising among the Allegheny Plateaus and Appalachian Ranges,[a] gathers its waters in a main channel which crosses the grain of the country in a southeasterly course. Its mouth is an estuary, a branch of Chesapeake Bay. Washington is situated at the head of tide water, where the estuary receives the river proper. The stretch from Washington upstream to Cumberland, a distance of 108 miles in a direct line and 186 miles by the river, is the trunk channel. The Shenandoah, Great Cacapon, and South Branch are its principal feeders. They enter from the southwest. North Branch is the actual head of the river. The tributaries from the northeast are relatively short, Wills Creek, Conococheague Creek, and Monocacy River being the principal ones.

Although the Potomac watershed is a mountainous region, characterized by ranges of notable height and continuity, it is not limited by the greater elevations. We are apt to think of the basin of a river as an area surrounded by a high or at least obvious divide, but that is not true of the Potomac. Its trunk channel cuts across the ranges; its branches embrace them; its headwaters in North Branch invade even the plateau whose bold scarp suggests an unbroken divide. The principal streams rise in valleys which extend with undiminished width and without change of the gentle slope beyond the head springs. In their continuation other springs and brooks gather and flow in a direction opposite to that taken by the waters of the Potomac. The parting streams are opponents, which compete for territory. The basin which the Potomac may drain is limited by its competitors. The Susquehanna holds the valley of Pennsylvania, the James is entrenched in southern Virginia, and the Big Kanawha and Monongahela contest the western plateau region.

The shape of the Potomac drainage basin west of the Blue Ridge is oval; its length, northeast to southwest, being 160 miles and its width

[a] Powell, J. W., Physiographic regions of the United States: National Geographic Monographs, vol. 1, No. 3, 1895, map.

but 80 miles. In consequence of the great length of the southern tributaries, the trunk channel crosses the northern part of the basin and leaves the oval at its northeast corner, where it and the brooks that join it constitute a triangular expansion of the watershed.

The arrangement of streams within the watershed deserves notice. By a study of the outline map (Pl. II) it will be seen that there is a peculiar parallelism among the many rivers flowing to the northeast or southwest, and also a marked tendency to courses which for short distances are at right angles to the general direction. The arrangement is a common one in certain regions, and a stream system thus developed is known as "trellised drainage," from the resemblance which the rivers bear to the stems of a vine on a trellis. While a trellised plan exists in much of the Potomac basin, it does not extend throughout. Another plan is to be noted, for example, in the Monocacy, Goose Creek, headwaters of the Shenandoah, and highest forks of North Branch. This is a plan characterized by acutely branching streams which divide as do the limbs of an elm tree.

Trellised drainage of the Potomac is restricted to the Appalachian Ranges and results from the grain of the country; that is to say, from the fact that the rocks are arranged in layers which show their edges at the surface and thus extend long distances in one direction. Some are hard (sandstones) and some are soft (shales and limestones). Ridges persist on the hard belts as valleys develop on the soft rocks between, and the streams for the most part follow the grain. There are conditions, however, under which they must cross from one valley to another, which they do in a gap at right angles to the sandstone ridge; hence the short, transverse courses at right angles to the longitudinal ones.

Where the rocks which appear at the surface are of the same texture and solubility over a considerable area, the streams find no belts especially adapted to the development of valleys; neither are there any harder layers peculiarly competent to maintain ridges; and in engraving the bas-relief of hills and ravines, the streams grow according to minor accidents of the surface, as gullies grow in a field.

Specific names have been given to the various patterns which river systems assume. Where the valleys are developed on belts of soft rocks, and ridges are maintained by hard rocks, the streams are said to be "adjusted." Trellised drainage is adjusted. Where the branches diverge upstream from one another like the gullies in a field or the branches of an elm, they are called "self-grown," or "autogenous." The Monocacy presents an example of the autogenous pattern.

We have thus far considered the plan of the Potomac system as it appears on a map. The vertical profile and cross section also present significant peculiarities.

79°30'
79°
Bloomington
Piedmont
Keyser
Potomac R.
North Branch
Patterson
South Branch
Moore
ALLEGHENY FRONT
North Fork of S. Br. Potomac R.
Potomac River
Moorefield
South Branch
North
Middle
River
Lewis C.
Stanton
South
79°30'
79°

leal river profile is a curve which descends sharply near the becomes flatter and flatter, and at the mouth is a straight ngent to the level of discharge. The ideal curve is concave l from source to mouth. The Potomac departs very decidedly iis ideal. The trunk channel from Cumberland to Washington rupted by rapids, which separate long flat reaches; at each he profile is broken by a sharp bend, which is convex on the side—the reverse of the ideal. Near the very mouth of the Great Falls, over which the waters plunge to a series of lesser that descend sharply to tide water. This is not at all the tangent. (See profiles, Pls. V and VI, p. 182.)

tributaries exhibit profiles possessing similar irregularities, is particularly noticeable throughout the system that wher- smaller stream enters a larger one a rapid or cascade marks il descent of the smaller.

ideal cross section of a river valley is, like the ideal profile, a vhich is concave upward and flattens from the divide to the . In this respect also the Potomac and its tributaries depart ie normal. The cross sections of the valleys are made up of lopes and flats, which constitute an irregular curve. Descend- eply from a divide, the traveler comes upon a flat or plain, may extend for several miles. Although the surface of the is a rule deeply cut by brooks, the journey may be continued at a level by following the spurs between them. But wher- stream, large or small, is approached, it is necessary to descend into a trench. Along the lower Potomac, below Great Falls, nch is a picturesque canyon 220 feet deep. The flat on each it is an outer valley several miles across. Along the Shenan- milar features are found, the river flowing at the bottom of a while the broad plain of the great valley of Virginia stretches vith nearly level though dissected surface to the Blue Ridge assanutten Mountain.

DEVELOPMENT OF THE RIVER SYSTEM.

igh has been suggested in the preceding description to show ie Potomac and its tributaries are regarded as an individual system which has developed from some previous condition present proportions. It has been limited in growth by com- n with neighboring rivers. Its development has been directed lines of least resistance and its branches have extended in f weak rocks. It has sculptured the surface, its rills, rivulets, , creeks, and branches everywhere constantly taking some al in solution or as sediment and delivering it to the trunk , which carried it away. The features which the river has d are the channel or inner canyon in which it flows, the

broader valley that expands at a higher level, and the steep slopes of the ridges that rise within and around the basin. But these are the features of the entire landscape, except perhaps the highest parts of the ridges; and they, too, owe their long level crests to the activity of the river, as will be better understood when the history is traced.

We recognize that the Potomac has been, and indeed is, a working, growing system. Its task is to excavate its basin, to erode valleys and mountains till no elevations remain. Its power depends on its volume, its fall, and a just proportion of sand with which to cut away the hard rocks in its course.

The trunk channel being deepened, the tributary channels have also been cut down, but not so speedily; hence the rapids near their mouths. The deepening, spreading from the main stream to large branches, from the large branches to their forks, and from each fork to the smallest rivulets, has extended outward over the entire basin. It proceeds immediately from an elevation of the land. Its limit is the lowest level to which the main stream can cut its channel at its mouth—the level of discharge, from which when the work of channel cutting is done the profile will rise in the long ideal concave curve. A stream that has reached that stage is said to be graded. It is evident that the Potomac has much work to do before it can be called a graded stream.

The channel of the main river will usually become graded before those of its tributaries, and the next step is the grading of the valley slopes. Each brook, rivulet, and rill goes through the same process as the main stream. The effect is reduction of the slopes to the inclination on which the waters flow but do not cut. As the grade extends to the higher divides, even they are reduced, and in time the lowest possible slope is established over the entire surface of a river basin.

Anyone familiar with the mountains among which the Potomac flows may well pause to ask if such a leveling of their heights can ever be accomplished; but the student of the river's history learns not only that in time they must be leveled, but also that in times past the river has had the work then before it much more nearly accomplished than now. It now runs in a canyon which it is deepening. It once flowed on the level of the outer valley, which it had cut to that level and widened to an extensive grade. Indeed, long before that it had taken its course over a plain which coincided with the tops of the present ridges and which it had graded from still older mountains.

The history of the river's work has been one of successive gradings in consequence of successive elevations of the land. Let us attempt to follow its major outlines.

Age is a subject not usually discussed with reference to rivers and

mountains. They all appear very old. But some are older than others, and among the rivers of North America the Potomac and its neighbors are of an older generation. The Appalachian Ranges, on the other hand, are relatively young; and so it happens that the Potomac is older than the mountains in which it rises and across which it flows. It may, however, be compared to a tree of which the trunk is aged, while the branches and branchlets are younger, some of them very young. The careful student of physiography will some day search out the history of the system as a whole and of each branch separately—a complex study, for which the data are not yet available; but we can indicate the principal facts and, where our present knowledge halts, point out the problem to be attacked.

Before there was a Potomac, in the age of the coal deposits of the Carboniferous, streams flowed southwestward from New York, eastern Pennsylvania, and eastern Virginia toward the interior sea that lingered over the Southwestern States. We feel confident of this, because the relative positions of land and coal marsh and sea are recorded in the rocks laid down at the time, but we can not identify the position of any particular river. There were then no mountains where the Appalachians now extend, but ranges began to develop in the next succeeding epoch, during what is known as the Appalachian revolution. Very great changes occurred in the relative positions of land and water, and the movement of the earth's crust was such that a belt of strata 100 miles or more in width, extending from New York to Alabama, and from 10,000 to 30,000 feet thick, was folded so as to produce arches and troughs. The effects were no doubt of gradual development, but in all probability they were such that the arches attained the height of notable mountains, and the troughs became open valleys or inclosed basins. The previously existing streams were more or less checked and diverted by folding of the strata, and we suppose that they were so effectually changed that a new river system was substituted for them. A portion of that system flowed on a surface above the Potomac basin, and the Potomac is probably descended from it.

The geologic age referred to in the last paragraph is the Permian, an age during which aridity was a common, if not a general, condition of the climate of several continents. It is possible that the climate of the Appalachian province was for a longer or shorter epoch so arid that rivers ceased to flow, but there is no direct evidence of the condition.

We suppose that the oldest rivers, which developed courses on the surface of the folded strata, flowed along the troughs and across from trough to trough, between and across the arches that stood as mountain ridges. The courses were essentially parallel to those of the trellised system of the present time, but the trunk channel may

have led the waters westward toward the interior sea, instead of southeastward to the Atlantic, as is now the case.[a]

The surface was then several thousand feet above the present surface. Even the mountain tops which we now see were then deeply buried beneath solid rock and lay below sea level. A swelling of the earth's crust has since raised the mass of the Appalachian Mountains.

Thus the earliest rivers with which the Potomac may be related are those which developed in consequence of the folding that occurred in the Appalachian region during the Permian age. Their courses are supposed to have been determined by the troughs or valleys which resulted from folding, and they are therefore called "consequent."

Consequent streams are those which flow in the direction of slope that is due to folding or warping of the surface. They differ from adjusted streams in that they take their courses along a low line or down a slope instead of working out a valley in soft rocks. But in a region like that of the Potomac, where beds of hard and soft rocks occur in long parallel folds, a consequent system becomes an adjusted system at an early stage of valley cutting.

The folded structure of the Appalachian Ranges has been carefully studied, and we are able to locate the lines which were the bottoms of troughs in the Permian surface. Though high above the present surface, the deeper troughs closely corresponded in position with Massanutten Mountain, Great North Mountain, and South Branch Mountain. Rivers which occupied them flowed parallel to the present streams, but along and above the now existing mountain tops. The old valleys have become mountain ridges. This change is of frequent occurrence in the process of adjustment, as streams sink their channels through alternate hard and soft strata,[b] and there is no difficulty in understanding how the rivers that now flow by the sides of the former troughs, or even in valleys along the crests of arches which correspond with former mountains, are related to the old consequent system.

Another trough which should be mentioned is the valley of Georges Creek and North Fork above Bloomington. It is one of the deepest troughs in the Potomac basin, and we need not doubt that it was occupied by a branch of the consequent drainage, but on a valley bottom high above the present surface.

Following the line of thought suggested in the preceding paragraphs, we may state the simplest outline of the history of the Potomac in the following way: The Potomac is the descendant of a consequent drainage system which developed on the Permian surface during or after the Appalachian folding. Being established in a region which presents an alternation of decidedly hard and soft

[a] Davis, W. M., Rivers and valleys of Pennsylvania: Nat. Geog. Mag., vol. 1, 1889, pp. 222 et seq.

[b] Willis, Bailey, Topography and structure of the Bays Mountains: School of Mines Quarterly, vol. 8, 1887, pp. 242–252.

cks arranged in long, narrow belts, the streams have become ljusted to the softer strata. In sinking their channels down urough several thousand feet of varying rock they have indeed ecome so thoroughly adjusted that stretches beneath the old valleys ave become mountain ridges capped with hard sandstone, and val-eys are developed on either side, in places even along the tops of rches.

Granting this statement the advantage of being probably true, we may compare it with one that we are descended from Adam. Many links are omitted and much is unaccounted for. It is not enough to know the structure of a river basin and the adjustment of the river system to it. We need to know also the profiles and cross sections of the valleys and the deposits which the river from time to time in the course of its long existence has made in them, as well. Furthermore, we need to look over the mountain tops to ascertain what remnants of old surfaces are there visible.

To pursue the subject more closely it is necessary to digress to the history of the mountains before the elevation of the ranges which we now see.

The Permian Appalachians are known to have been greatly ele-vated in the process of folding. It is possible that elevation pro-gressed so slowly that erosion nearly kept pace with it in wearing down the heights, and if so, the mountains never attained great alti-tude; but it is more likely that the elevation went on with compara-tive rapidity and was attended by the development of conspicuous heights. This inference rests, however, on geologic reasoning. There are no great mountains to which one, looking abroad over the Appalachian Ranges, can point as Permian mountains. On the con-trary, he who looks across from Massanutten to Great North and from Great North to the Allegheny Front sees long, even-crested ridges, which suggest a plain. If the valleys were filled to the rim with the material which the streams have carried away, the region would become a plain; and above such a surface stood the mountains of Permian time. They are no longer there.

In the lowlands of New Jersey, eastern Pennsylvania, Maryland, and Virginia there are deposits of red sandstone and mud rock, the materials of which were derived from adjacent areas, in large part from the district of the Permian mountains. The strata are Triassic, slightly more recent than the Permian, and are of such volume that if restored en masse to the place of their origin they would form a con-siderable mountain chain. They no doubt represent a part of the Permian mountains which wasted away under attacks of eroding agents.

It is a somewhat surprising conclusion that the Permian Appa-achian Mountains not only wasted to low hills, but disappeared so

completely that a plain extended from sea level across much of the region where they previously stood; yet that such was the fact we are led to believe by two lines of reasoning. Spread over the Atlantic Coastal Plain are deposits of gravel, sand, and clay washed from the region to the west during the epochs succeeding that of the strata which represent part of the waste of the Permian Appalachians. Geologists class the epochs as Jurassic and Cretaceous. The deposits are small in amount, and if restored to the watersheds of the streams which carried them away would not materially increase the altitude of the surface. As there is no mass of sediments of that time equivalent to a mountain range in volume, we reason that there was no range. The only escape from the conclusion is through the assumption that thicker deposits lie buried out to sea; but well borings show that the strata which do exist there are of fine calcareous material, chiefly marine sediment, which does not represent the immediate waste of mountains.

In corroboration, if we look over the Appalachian Ranges for remnants of highlands which may have existed during Jurassic and Cretaceous times, we find them of slight extent. The principal summits of the Blue Ridge, scattered heights of the Allegheny Plateaus, and the big balds of the Great Smoky Mountains were then low, rounded hills.[a] They still possess that form. Extending from them at a lower level are the long, even crests of the Appalachian Ranges, which, if the valleys between them were filled, would correspond with the surface of a plain. Once nearly level, this plain is so no longer. In West Virginia it lies at an altitude of 4,000 feet above the present sea level, but west of Washington it sinks to 1,000 feet, and near the city passes under the surface, being buried by the gravels and clays of the so-called Potomac formation, which is at the base of the Jurassic and Cretaceous sediments above referred to. The topographic features of the time are thus distinguished from those of later epochs by the fact that in the existing mountains they possess peculiar roundness and flatness and occur at high altitudes, whereas along the Coastal Plain the representative surface passes beneath the strata of later age.

The recognition of the ancient plain which characterized the eastern United States and also Canada during the Jurassic and Cretaceous ages was a most important step in the understanding of the history of the mountains and rivers. From its conspicuous character in the crest of Schooley Mountain, New Jersey, it has been named the Schooley peneplain.[b]

[a] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, 1894, pp. 63-126, Pl. V.

[b] Peneplain is a technical term meaning almost plain. It is used to avoid the suggestion of a perfectly plain surface. It is consistently applied to a region of wide valleys among low hills, or to a true plain, the degree of unevenness being indeterminate; but it carries by definition the implication that the surface has been planed by the ordinary processes of atmospheric erosion.

We may now return to the Potomac, to discover, if possible, its course on the Schooley peneplain and to trace its further development.

It has already been stated that the consequent drainage of the Permian Appalachians probably joined in a trunk channel and flowed to the southwest. The Potomac above Harpers Ferry could not then have existed, except perhaps as a stream rising in the Blue Ridge and pursuing a course toward Cumberland. The Shenandoah, South Branch, and other large tributaries, which are now adjusted to the valleys in limestone and shale, were then represented by streams flowing along the troughs produced by folding. By the time the Permian Appalachians had wasted to a peneplain still having pronounced relief the adjustment of the branches was accomplished and they were probably established along the lines of their present valleys, but near the level of the now existing sandstone ridges. The trunk channel may still have descended westward. East of the Blue Ridge there were rivers that carried down sediment to the Coastal Plain and spread it there. Part of it constitutes the base of the Potomac formation, and consists of coarse pebbles and bowlders of quartz and quartzite derived from ledges in the Blue Ridge. It was distributed by streams meandering over the eroded surface of the ancient gneisses, with the sands of which the cobbles are mingled. A river corresponding with the Potomac below Harpers Ferry probably had a more or less important share in this work, which was accomplished during the later part of the Jurassic age. It is possible that the river even then rose west of the Blue Ridge.

When the Schooley peneplain had been eroded to very low relief, conditions were favorable for extension of drainage lines on the part of strong streams at the expense of weaker ones. The processes by which such extension is accomplished are complex and subject to many qualifying conditions. They can not be detailed here, but in general there are three principal factors which affect the result.

A river of large volume is commonly stronger than one of less volume. One which has rapid fall—that is, one which takes a short course to a low point of discharge—is advantageously situated. Finally, one which is developing a channel in soft rocks is likely to reach a low level sooner than one which is working in hard rocks, and may thus develop a steep fall near its head, which gives it a local advantage.

In attempting to understand how the consequent drainage that initially flowed westward became reversed, so that the present direction of flow was established, we find that the item of relatively short course and steeper fall appears to have been the determining factor. Whether the divide be assumed at the Blue Ridge or at any other point within the Potomac basin, the course to tide level near Washington is much shorter than that toward the southwest, in which

direction there was then, so far as we know, no sea nearer than the Gulf of Mexico, if as near. The eastern course, being shorter, was steeper, and streams pursuing it attacked the divide between themselves and western rivers more vigorously than the latter did. The rocks of the Blue Ridge are hard and no doubt formed a height which long resisted the work of the gnawing brooks that ran down its eastern slope; but inasmuch as it was leveled to a low ridge by the very slow process of general denudation, it must have yielded sooner to the more effective abrading action of running water and sand.

At some time, probably early in the development of the Schooley peneplain, the Blue Ridge was thus cut through from the east. This result follows directly from its geographic position in relation to tide water, but it may have been accelerated by elevation of the western or depression of the eastern region in such a way as to increase the advantage of the eastward course. Davis, who first recognized the reversal,[a] suggests that it occurred when the basin in which the Triassic sediments from the Permian Appalachians were deposited was developed, in which case the present course of the Potomac has been established since Triassic time instead of only since late Jurassic or early Cretaceous.

The Potomac at Harpers Ferry was not the only stream which succeeded in crossing the ridge. Each of the several gaps that notch the Blue Ridge, as, for example, Snickers Gap at the head of Goose Creek, though a wind gap now, was a water gap then, and was occupied by the successful stream. The Blue Ridge being cut through, the eastern waters were divided only by limestone from the rivers which drained the Great Valley, and having gained ground in the contest for the main divide, they were able to continue doing so; but as the hard rocks of the Blue Ridge lay across their upper courses their progress beyond was probably slow at first, until they had cut the gaps below the general level of the peneplain on the limestone. That they should eventually expand in the Great Valley and capture the streams which still formed the headwaters of the westward-flowing main river was an inevitable result of their shorter course to the sea. The development of several systems, among which the basin of the present Potomac was divided, was a natural result.

The preceding explanation of the growth of the Potomac across the Blue Ridge and beyond to the Allegheny Front is based on a well-known action by which streams grow at their heads as a tree grows at the tips of twigs. It is technically known as "headwater" erosion or "retrogressive" erosion.

A somewhat different account of the development of the Potomac may be based on what is known as a "superimposed" course. If it be assumed that the Schooley peneplain was covered with alluvium to a

[a] Davis, W. M., Rivers and valleys of Pennsylvania: Nat. Geog. Mag., vol. 1, 1889, p. 229.

sufficient depth to bury the lowest parts of sandstone ridges, then it is probable that streams would become established across the ridges as well as between them. Transverse channels would develop rapidly if the plain were so warped as to increase the declivity toward the east. In the progress of warping the deepening channel would be cut down to hard rocks, but the river would then be intrenched and could not depart from its established course across the grain. This process implies very uniform planation of the surface, and might have led to a less direct course than that which the Potomac has; but it may have played some part in the river's early history, as it probably did in some later episodes.[a]

Leaving the problem of the exact manner of development to the careful investigation which it merits, we may consider the course of the Potomac from Cumberland to Harpers Ferry as having been established on the Schooley peneplain. The trunk channel was then fed by tributaries which entered it as the principal branches now do, and the system was one which may fairly be called the "Potomac." It did not, however, have the expansion of watershed which it now has, but was probably much more restricted toward the south, the Shenandoah, South Branch, and others on that side being at the time comparatively short. The northern branches, on the other hand, may have been longer.

In the preceding discussion one important fact has been tacitly passed over—the altitude of the Schooley peneplain at the time of its development with reference to sea level. The evenness of the plain is attributed to planation by streams, which are able to produce such a surface only when they have cut their channels down to the lowest possible grade—that is, to a slope which is tangent with the sea level or with some other fixed level of discharge. A barrier of hard rock, a dam, for instance, may for a time constitute a local level of this sort. The Schooley peneplain is so extensive that no local level can have sufficed to fix it. Sea level alone could determine the grade common to many streams draining thousands of square miles. We reason accordingly, from the laws of river action and the extent of the peneplain, that the surface of the land rose gradually from sea level to a very moderate altitude only. This was in the Jurassic and Cretaceous periods.

At the present time the Schooley peneplain in West Virginia lies at an altitude of 4,000 feet and its surface has the form of a very broad, somewhat uneven dome, sloping from the greatest height in that region to a position below the Coastal Plain on the east and to one nearly as low in the Mississippi Valley on the west. It is a warped

[a] Willis, Bailey, The northern Appalachians: Physiography of the United States: National Geographic Monographs, vol. 1, No. 6, 1896, p. 190.

surface, raised on a gentle swelling of the underlying rocky crust from the low grade at which it was developed to its present form. The consequences of elevation where streams flow upon swelling surfaces are increased velocity of flow and deeper cutting of the channels. Large rivers may do so nearly or quite as rapidly as the mass beneath them rises, and may thus maintain a relatively low grade at the bottom of a canyon; but smaller streams do not keep pace and acquire steep profiles. At their headwaters the branches tend to grow as their channels deepen; competition is renewed between opponent brooks across a divide; and if the changed conditions favor one more than another the favored one grows accordingly. Furthermore, rivers flowing across rock masses which consist of alternate hard and soft layers sooner or later cut down to a change of rock, from soft to hard, or vice versa, and thus become favored or retarded in the process of deepening their channels. The advantages thus gained or lost lead to readjustments of watersheds—a kind of natural gerrymander, to borrow a political phrase—and to the diversion of streams from one course to another by the process known as stream capture.

The growth which the Potomac and its tributaries had in consequence of the doming of the Schooley peneplain resulted in the existing arrangement, which probably differs notably from that of the older river. The detailed changes within the Potomac basin escape our present knowledge, but they may be more or less closely traced by study of the wind gaps, which represent abandoned channels, and by investigation of the relations which streams had to the underlying rocks during the process of sinking their valleys from the level of the mountain tops to their present position.

One fact is, however, so striking that it stands out clearly—the great length of the southern tributaries of the Potomac as compared with the opponent streams that flow to the James. The headwaters of the Shenandoah, for example, in Augusta County, 120 miles from the Potomac at Harpers Ferry, are but 25 miles from the James at Balcony Falls. A sufficient reason is found in the fact that the warped surface of the Schooley peneplain slopes toward the Potomac. It is highest above the region where the divide extends between the Shenandoah and South River (the opposing tributary of the James),[a] and the long course of the Shenandoah corresponds with the long slope of the old surface. The inference is that the Shenandoah grew to its present dimensions because, when it was a much smaller river, its fall was increased by the northward tilting of the surface. Having a low point of discharge it extended its basin by headwater erosion, capturing in succession the heads of those streams which rose in the Great Valley and flowed eastward across the Blue Ridge. Their

[a] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, 1894, Pl. V.

abandoned gaps, such as Snickers Gap, remain as evidence of their former existence. In the course of its conquests the Shenandoah became opposed by the tributaries of the James, but it continued to push the divide southward until an equilibrium was established between the opponents across the area where the Schooley peneplain was most elevated.

The northern tributaries of the Potomac are short as compared with the southern branches of the Susquehanna opposed to them. They were at a disadvantage, as their fall southward was lessened by the rise of the northward slope of the peneplain, and they lost ground to the Susquehanna, as the James did to the Potomac.

The doming of the Schooley peneplain has been a gradual process, involving in the Virginias a maximum change of level of about 3,500 feet. As the uplift progressed the Potomac developed a canyon which in due process widened to a valley. Had the uplift been accomplished and ceased long ago, the valleys would be very wide, especially along the master stream, and much of the region would be eroded to grade. Had the upward movement been continuous, the river would exhibit a simple profile and the valleys simple cross sections, generally concave upward and broken only by hard beds of rock, which would project above the average slope. Neither of these cases corresponds with the facts. There are wide valleys, but within them are narrow canyons. The greater width was developed when the stream had worked down to grade during a pause in the elevation; the narrower channel was sunk when the activity of the river was renewed by renewed uplift. Thus it is apparent that warping has been an intermittent process.

At every stage of sculpture through which the surface passed, the Potomac and other streams bore to their lower courses the sediment taken from upper districts and spread it upon the Coastal Plain or delivered it to tidal waters in estuaries or the open sea. The volume of sediment and its character, whether coarse or fine, varied with the rate of uplift. The strata are thus a record of the river's work and indirectly of the height of land. Something may be inferred from them regarding the rate of warping. There is, however, another factor which complicates the problem—variation of climate, according to which the river's volume, and consequently its ability to carry sediment, changed from time to time. Though probably subordinate to uplift, it is not negligible. Bearing in mind that there are two factors which have determined the river's action, the careful student may investigate the sediments on the one hand and the valley profiles on the other and work out a more detailed history than we now possess. At present we are not able to describe the successive stages accurately, but certain marked ones stand out clearly with such

decided character that we can with confidence attribute them to the more effective of the two variable factors, the progress of uplift.

The wide valley of the Shenandoah marks the earliest pause in excavation of which there is record in the sculptured surface. No general view of it can be had from the river, which, near its mouth, in consequence of later cutting, runs 350 feet below the valley level, but it may be inspected from any of the numerous low shale hills that diversify the former valley plain. It is not difficult, when looking down on the river's turbid flood, to realize that it has sunk its channel among the hills. It is but another step to recognize that if we could restore what the river and its branches have carried away the hills would be joined together by the fills and the whole wide valley would present a plain. That it once did have such a plain surface, which was worked out to the grade of the river, is not questioned, and the laws of river action lead directly to the conclusion that the level of discharge which the river then had was the level of the plain near its mouth.

From its characteristic development in the Shenandoah Valley the valley plain has come to be known as the Shenandoah. It is not, however, a local feature, but a surface which is present throughout the Appalachian Mountains wherever the rocks are soft shale or the even less resistant limestone.

As the Shenandoah plain is thus a general fact of sculpture, to a greater or less extent worked out by all the rivers of the region, its grade could have been determined only by a common level of discharge—sea level—and a plain of such wide development as it exhibits could not have been sculptured while the level of discharge was changing in course of uplift, but only during a prolonged interval of constant level. We divide the uplift and erosion of the mountains accordingly into an earlier cycle, during which valleys were sunk 1,000 to 2,000 feet below the Schooley peneplain in the Potomac region and the Shenandoah plain was eroded over all the areas of softer rocks, and the later cycles, during which the lower features of the valleys have been cut.

During the earlier or Shenandoah cycle the Potomac and its southern branches grew very nearly or quite to their present lengths; the northern branches diminished as they gave ground to the Susquehanna; and thus the competing streams established the watersheds that now exist. North Branch of the Potomac held a very advantageous position in opposition to the western streams on the plateau, as it reached a relatively low level on soft rocks in a much shorter distance than they. It was therefore able to extend such branches as Savage River and Crabtree into their territory, and it is still doing so.

The Shenandoah plain (recently rechristened the Harrisburg pene-
in[a]) no longer exists as a continuous surface. Cut by the larger
ers and their branches, even out to the smallest, it is represented
y by hilltops that approach its level. Its altitude near Harpers
rry is about 600 feet above the sea; about the headwaters of the
enandoah it is 1,200 feet. Between it and the channel of the
er, 200 to 350 feet below, are sculptured the terraces and slopes
later development. Among these is a lower valley level, about
) feet below the Shenandoah plain, which apparently corresponds
a surface that extends about Somerville, N. J., and is known as
) Somerville peneplain.[b] It is eroded on the limestones or very
t Triassic sandstones and represents a shorter pause in the progress
uplift than did the Shenandoah.

The Shenandoah and Somerville plains are not everywhere dis-
guishable one from the other, being represented in some places by
e extensive surface. Toward the close of their development, in
e epoch known to geologists as the late Tertiary or Pliocene, they
came covered by a widespread deposit of gravel and loam, which
called the Lafayette formation.

The Lafayette covers the outer slopes from the Appalachian Moun-
ns toward the Atlantic and Gulf coasts and the Mississippi Valley
th an almost continuous mantle. It is represented in the dis-
cts of the Appalachian Ranges and Allegheny Plateaus by deposits
gravel that now cap terraces and hills. It is composed through-
t of alluvial material, carried, sorted, and deposited by streams in
e first instance and to some extent rearranged by marine waters
out the margins. What part is fluviatile and what part marine is
be determined only by further studies; but it is probable that the
tivity of rivers in spreading the material has been underestimated
d that the degree of marine submergence has been correspondingly
erestimated. The Potomac, like other rivers of the Lafayette
och, flowed in a wide alluvial plain, which coalesced with those
adjacent rivers in the lower courses.

The epoch of low, level, and wide-spreading plains was followed by
e during which the land was again elevated and the rivers incised
e channels they had assumed. It is probable that the elevation
as not constant, especially in the outer Coastal Plain, for there is
idence that the lower valleys were at times submerged after having
en eroded.[c] Other influences were, however, almost if not quite
important. It was the time called Pleistocene, the time of the

[a] Campbell, M. R., Geographic development of northern Pennsylvania and southern New York: Bull. Geol. Soc. America, vol. 14, 1903, pp. 277–296.

[b] Davis, W. M., and Wood, J. W., jr., Geographic development of northern New Jersey: Proc. Boston Soc. Nat. Hist., vol. 24, 1890, pp. 391–392.

[c] Darton, N. H., Washington folio: Geologic atlas U. S., folio 70, U. S. Geol. Survey, 1901.

glacial and interglacial epochs, when the climate varied from temperate to semiarctic and back to temperate again; the rivers changed their activities accordingly and alternately cut their channels or partially filled them. The minor gorges that characterize all the valleys, the cascades that beautify the rivers, and the wide rocky shallows that are peculiar features in streams so large as the Potomac and Susquehanna resulted from these activities, as did also the later gravel and silt deposits constituting the Columbia formation, which are extensively spread upon terraces along the Potomac, especially in the vicinity of Washington.

As we approach the present, the seeming importance of details increases. The deposition of the Columbia formation, for example, marks an episode which seems to compare with the erosion of the old Permian mountains, though it is indeed a relatively insignificant fact. But every detail of the river's course or profile or deposits is significant of some past circumstance, if we can but understand.

Old as the Potomac is and varied as have been the activities affecting its development, a new agent has appeared in its watershed within the last three hundred years and is acting as the chill climate of the ice age acted to denude the surface and load the river with sediment. Throughout the Tertiary age, when the Schooley peneplain was cut away, when the Shenandoah plain was graded, and when the inner canyons were sculptured, the region constantly bore a luxuriant deciduous forest, in which the tulip tree and the magnolia appeared at an early date and the more modern oaks and maples and many others found place later. With the advent of the ice age the climate changed from semitropic to temperate, and then to that of the Barren Grounds of the Far North to-day. Vegetation died; the surface was bared; rain or waters from melting snow swept away the frost-loosened earth; winds carried the dust in eddying clouds; the rivers were surcharged with sediment, and the Columbia deposits resulted. The new agent in his own peculiar way is preparing another such deposit. He has bared the surface almost as effectually as did the blasts of the ice age, but with an ax only, and he is causing a new record to be made in the hills that are scored with gullies and in the lowlands that are buried beneath deposits of gravel and mud.

The Potomac's long history has been influenced by great forces—the internal energy of the earth, that has shaped the surface on which the river grew; the attraction of gravitation, that has caused the river to flow; the external force of the sun, that has set the atmospheric agents to work. They were sometimes conservative, sometimes destructive. The new force has demonstrated his capacity to destroy; in his own interest he needs to acquire the art to protect. The future of the Potomac and the fitness of its watershed to be a home for man depend on his intelligent use of what the ages have fashioned.

STREAM FLOW IN THE POTOMAC BASIN.

By R. H. Bolster.

INTRODUCTION.

METHODS OF WORK.

FIELD METHODS.

The methods by which the records of stream discharge have been made are those in common use in the United States Geological Survey. They are described in detail in Water-Supply and Irrigation Papers Nos. 94 and 95 and briefly in the annual progress reports for 1904 to 1906. An outline of the method used in the Potomac River drainage basin is given below, to assist in making clear the data which follow.

A gage for observing the stage of the river is established at a bridge or other place where the record of flow is to be made. This gage is a vertical staff or some other device by which the height of water may be observed, and is read each day by a person living near by. The average of the gage readings, if more than one, in any day is used as the mean gage height for that day.

At various stages of the river one of the hydrographers of the Survey visits the station and measures with a current meter the amount of water flowing. This meter is primarily an instrument for measuring the velocity of moving water, and consists essentially of a wheel with vanes, which may be shaped like those of a windmill or of a screw, or with cups like those of an anemometer, the necessary qualification being that moving water shall readily cause the wheel of the meter to turn. Each meter is rated before use. The rating is done by moving the meter through still water at various observed speeds to determine the relation between the velocity with which the meter moves through the water and the revolutions of the wheel. This relation having been determined, the meter is used in running water, the revolutions per unit of time noted, and the velocity of the water computed.

Observations of depth of water are also made, and from them the area in cross section of each portion of the stream is computed; each

partial area multiplied by the mean velocity of that area gives a partial discharge. The sum of the partial discharges is the total discharge of the stream.

OFFICE METHODS.

Measurements of flow as outlined above are made covering a considerable range of gage height. They are then plotted on coordinate paper, with gage heights for ordinates and discharges for abscissas, and a smooth curve, called the rating curve, is drawn through the points. From this curve a rating table is made which shows the discharge of the stream for any gage height.

The data necessary for the construction of a rating table for a gaging station as just stated are the results of the discharge measurements, which include the record of stage of the river at the time of measurement, the area of the cross section, the mean velocity of the current and the quantity of water flowing; and a thorough knowledge of the conditions at and in the vicinity of the station.

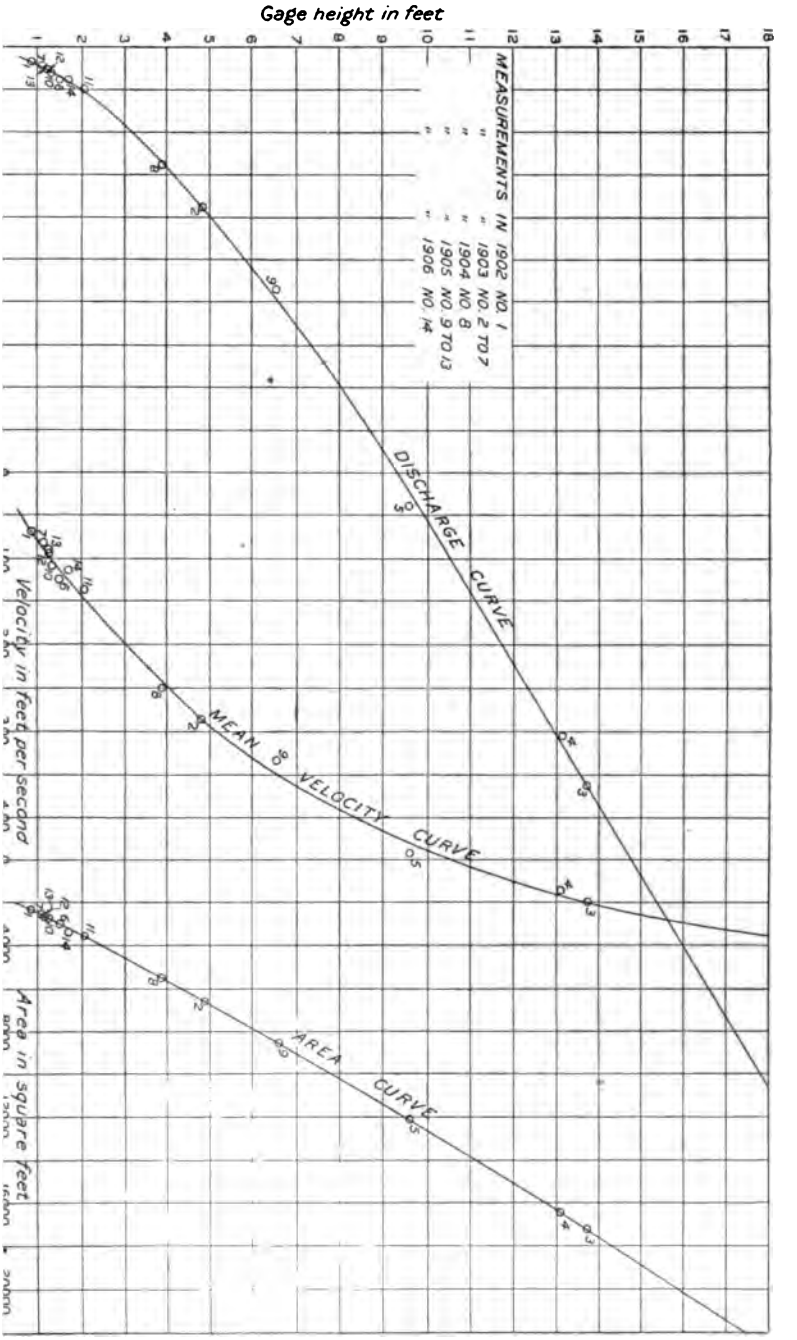
The construction of the rating table depends on the following laws of flow for open permanent channels: (1) the discharge will remain constant so long as the conditions at and near the gaging station remain constant; (2) the change of slope due to the rise and fall of the stream being neglected, the discharge will be the same whenever the stream is at a given stage; (3) the discharge is a function of, and increases gradually with, the stage.

The plotting of results of the various discharge measurements, using gage heights as ordinates and discharge, mean velocity, and area as abscissas, will define curves which show the discharge, mean velocity, and area corresponding to any gage height. For the development of these curves there should be, therefore, a sufficient number of discharge measurements to cover the range of the stage of the stream. Fig. 1 shows a typical rating curve with its corresponding mean velocity and area curves.

As the discharge is the product of two factors, the area and the mean velocity, any change in either factor alone will produce a corresponding change in the discharge. Their curves are therefore constructed in order to study each independently of the other.

The area curve can be definitely determined from accurate soundings extending to the limits of high water. It is always concave toward the horizontal axis or on a straight line unless the banks of the stream are overhanging.

The form of the mean velocity curve depends chiefly on the surface slope, the roughness of the bed, and the cross section of the stream. Of these the slope is the principal factor. In accordance with the relative change of these factors the curve may be either a straight line, a curve convex or concave toward either axis, or a


Gage height in feet
MEASUREMENTS IN 1902 NO. 1
" " 1903 NO. 2 TO 7
" " 1904 NO. 8
" " 1905 NO. 9 TO 13
" " 1906 NO. 14
DISCHARGE CURVE
MEAN & VELOCITY CURVE
AREA CURVE
Velocity in feet per second
Area in square feet

combination of the three. From careful study of the conditions at any gaging station the form which the vertical velocity curve will take can be predicted, and it may be extended with reasonable certainty to stages beyond the limits of actual measurements. It is used principally in connection with the area curve in locating errors in discharge measurements and in constructing the rating table.

The discharge curve is defined primarily by the measurements of discharge, which are studied and weighted in accordance with the local conditions existing at the time of each measurement. The curve may, however, be best located between and beyond the measurements by means of the curves of area and mean velocity. This curve under normal conditions is concave toward the horizontal axis and is generally parabolic in form.

In the preparation of the rating table the discharge for each tenth on the gage is taken from the curve. The differences between successive discharges are then taken and adjusted according to the law that they shall either be constant or increasing.

DEFINITIONS.

The volume of water flowing in a stream, the "run-off," is expressed in various terms, each of which is associated with a certain class of work. These terms may be divided into two classes: Those which represent a rate of flow, as second-foot, gallons per minute, and run-off in second-feet per square mile; and those which represent actual quantities of water, as run-off in depth in inches. They may be defined as follows:

"Second-foot" is an abbreviation for cubic foot per second, and is the rate of discharge of water flowing in a stream 1 foot wide 1 foot deep at the rate of 1 foot per second. It is generally used as a fundamental unit from which the others are computed.

"Gallons per minute" is generally used in connection with pumping and city water supply.

"Second-feet per square mile" is the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the run-off is distributed uniformly both as regards time and area.

"Run-off in inches" is the depth to which the drainage area would be covered if all the water flowing from it in a given period were conserved and uniformly distributed over the surface. It is used for comparing run-off with rainfall, which is usually expressed in depth in inches.

EXPLANATION OF TABLES.

For each regular station are given, as far as available, the following data:

1. Description of station.
2. List of discharge measurements.
3. Gage-height tables.
4. Rating tables.
5. Tables of estimated monthly and yearly discharges, run-off, and precipitation, based on all the facts available to date.

The descriptions of stations give such general information about the locality and equipment as would enable the reader to find and use the station, and, as far as possible, a complete history of all the changes that have occurred since the establishment of the station that would affect the use of the data collected. They also give statements concerning the probable percentage of error of the estimates. The probable errors have been based principally on the errors of the discharge measurements with reference to the rating curves.

The discharge-measurement table gives the results of the discharge measurements made during each year, and includes the date, the gage height, and the discharge in second-feet.

The tables of daily gage heights give for each day the height of the surface of the river above the zero of gage, as found from the mean of the gage readings taken on that day.

The rating tables give discharges in second-feet corresponding to each stage of the river as given by the gage heights and statements concerning the measurements on which it has been based and the portion of the curve which is well defined.

In the tables of estimated monthly discharges the column headed "Maximum" gives the mean flow for the day when the mean gage height was highest; this is the flow as given in the rating table for that mean gage height. As the gage height is the mean for the day, there might have been short periods when the water was higher and the corresponding discharge larger than given in this column. Likewise in the column headed "Minimum," the quantity given is the mean flow for the day when the mean gage height was lowest. The column headed "Mean" is the average flow for each second during the month.

On this, the computations for the columns under the general heading "Run-off" are based. The mean precipitation, which has been entered in the column headed "Precipitation in inches," for gaging stations which have been maintained for a series of years has been determined from the United States Weather Bureau records. The mean precipitation has been determined from well-distributed rainfall stations in the drainage basin above the gaging station.

From the precipitation in inches and the run-off in depth in inches the run-off in per cent of precipitation has been determined, also the loss of precipitation in inches or the amount which for several causes does not flow past the gaging section.

ACCURACY OF ESTIMATES OF STREAM FLOW.

The description of each gaging station is followed by a statement indicating the probable percentage of error in the values for mean monthly flow. This percentage is only approximate, as no refinement has been attempted in its determination. The probable errors have been based principally on the errors of the discharge measurements with reference to the rating curves and the known conditions of the flow in the vicinity of the gaging section. It is impossible to estimate closely the errors caused by temporary or gradual changes in the conditions of flow, unreliability or ignorance of the observers, changes in wire or chain length, or ice conditions.

Errors due to changes in conditions of flow are relatively small for the large streams except at a few stations. On small streams, however, a temporary obstruction at or below the gaging section, causing a change in area of cross section or in velocity of the current, may cause large errors in daily estimates of discharge. These changes as a rule do not occur frequently and are usually of a temporary character: for example, the lodging of driftwood on the controlling point below the gage reduces the velocity, and hence the discharge for a given gage height. A few days later a sudden rise in the stream may clear the channel and restore normal flow. Unless the hydrographer has chanced to make a measurement of discharge during the period of abnormal conditions, an error has been introduced into the monthly estimates. Owing to the limited appropriation for stream gaging and the large number and wide separation of the gaging stations, it is impossible for the hydrographers to make measurements frequently enough to eliminate all errors arising from these abnormal conditions. It has further been found impracticable to so instruct the observers that they will correctly report unusual conditions.

Gradual changes in the conditions which affect the flow can be estimated and corrected more readily than temporary changes. Here again the hydrographer is often handicapped by inability to make sufficient measurements to show properly the varying rate of change in channel conditions. In such cases the estimates are obtained either by an indirect method which is based on the assumption of a constant rate of change from day to day between measurements or by a series of rating curves.

Observers are as a rule conscientious in reading the gages, but with few exceptions they are wholly unfamiliar with engineering work of any description. The observers' records, however, are examined and

checked by hydrographers, and large errors are thus eliminated. The observers are usually instructed to read the gage to the nearest tenth or half tenth of a foot twice each day, and at times of floods several times a day. At high and medium stages the errors in reading the gage are thus negligible; but at low stages, when a difference of one or two hundredths in the stage of the river or slight fluctuations during the day cause errors of several per cent it is evident that the regular method of observation is inadequate. Hence, monthly minimums may be considerably in error; but in general the monthly means for months of low flow are good, owing to the tendency of positive and negative errors to offset each other.

Prior to the fall of 1903 wire gages were used at many of the stations for observing the stage of the river. The correct length of gages of this type was difficult to maintain on account of the stretching of the wire. Small changes of length took place frequently, making necessary the application of corrections to the observed gage heights at the station. In some instances the magnitude of the corrections and the time over which they should have been applied were not recorded, and the proper adjustments are therefore somewhat in doubt. In such instances, if the data warranted it, the gage heights were corrected by the amount that the measurements of the period in question were vertically above or below the curve. It is believed that by the use of corrected gage heights reasonably accurate estimates of discharge have been made for all the rivers described.

The extent of frozen periods at many of the stations is very uncertain. All ice notes are from observers' gage-height records, but as the observers' notes prior to 1904 are very incomplete their absence does not always imply open-channel conditions. Estimates for ice periods have been made as if open-channel conditions existed except as noted. This method involves errors for the relatively short ice periods of a few to 40 per cent.

The errors which are described above are not to be considered as applying to every station. They have been fully described here in order to call to the attention of the reader the possible sources of error and the limitations of engineering work of this kind. Although the resulting error may seem large, it should be remembered that stream-gaging data and estimates of flow are used mainly as a basis for predicting the maximum, minimum, and mean discharge which may be expected in future years. Since the mean annual flow of a stream may be several times larger one year than it is the next, it is evident that for records of short duration an estimate which involves an error as great as 50 per cent is not without value. On the other hand, it is a waste of money and needless refinement—indeed, virtually impossible—to obtain estimates much closer than 3 per cent in ordinary current-meter work.

Special emphasis is laid on the fact that the value of stream-gaging data is determined mainly by the number of years during which the record has been maintained and not so much by the degree of accuracy of the discharge for each year. That is, the longer the record the more nearly does it indicate the maximum, minimum, and mean flow which may be expected in the future.

Monthly means which are stated in the descriptions to be within 5 per cent of the true flow are considered to be very good, and those within 10 per cent are considered close enough for all practical purposes. Errors in estimates which are greater than 15 per cent are due either to an insufficient number of measurements, or to poor natural conditions which could not be avoided, or to changes at the gaging station which could not be foreseen at the time of its establishment. The larger errors in daily discharge values occur at the highest stages, which continue only for a few days, and hence the effect on the accuracy of the monthly mean is not so great as might at first appear. Also by far the greater number of gage heights are for medium stages, at which the error of the rating curve is seldom as great as 10 per cent and is usually much less than 5 per cent. The errors in the daily discharge values are often considerable, owing to fluctuation of the river height. The values for the maximum and the minimum flows for the month may also contain an additional error, because they are based on the extreme low or high part of the rating curve, which is usually not so well defined as the intermediate portion. In the case of the mean monthly flow, for which the estimates of accuracy are made, the error is reduced to a very small amount by reason of the compensation of variable negative and positive errors.

COMPARISONS OF FLOW.

The figures in the following table have been brought together for the purpose of comparing the flow from a partial drainage area with the flow from the total drainage area over a relatively long period of time.

The totals show that the ratio of the run-off from the tributaries to the run-off from the total basin is 6 per cent greater than the ratio of their respective drainage areas. This is entirely reasonable and just what should be expected, for during medium and especially during high stages the run-off is greater on the tributaries, owing to somewhat greater rainfall and more precipitate slopes.

In the comparison of the run-off from month to month it should be remembered that there is a considerable time interval between the stations. For example, a flood on the tributaries occurring at the end of a month does not reach the Point of Rocks station until the following month. It is believed that this accounts for most of the larger deviations of discharge from the normal for the individual months.

Mean monthly discharge in second-feet, Potomac River basin.

Date.	Potomac River at Point of Rocks, Md.	South Branch Potomac River near Springfield, W. Va.	Shenandoah River at Millville, W. Va.	North Branch Potomac River at Piedmont, W. Va.	Total, exclusive of Point of Rocks.	Ratio of discharge of tributaries to that of main stream at Point of Rocks.
1903.						
September	4,669	336	2,249	90	2,675	0.57
October	3,212	271	1,454	103	1,828	.57
November	2,175	206	961	134	1,301	.60
December	[a] 2,926	[a] 286	927	193	1,406	.48
1904.						
January	[a] 7,287	1,009	.....	643	.....	.....
February	[a] 17,480	1,004	.....	795	.....	.....
March	11,170	1,451	.....	1,433	.....	.....
April	7,506	1,660	2,191	937	4,788	.65
May	9,362	2,143	2,779	792	5,714	.61
June	10,160	1,121	2,430	392	3,943	.39
July	4,510	568	1,930	160	2,658	.59
August	2,394	238	1,096	37	1,371	.57
September	1,592	123	620	17	760	.48
October	1,164	81	521	28	630	.54
November	1,340	80	528	34	642	.48
December	2,201	[a] 296	780	243	1,319	.60
1905.						
January	[a] 8,626	[a] 821	2,065	360	3,246	.38
February	5,625	[a] 831	1,684	232	2,747	.49
March	23,480	4,793	4,387	2,484	11,664	.50
April	6,581	1,015	1,945	585	3,545	.54
May	4,493	1,744	1,382	496	3,622	.80
June	6,579	1,948	2,552	588	5,088	.77
July	10,190	1,673	2,994	653	5,320	.52
August	5,830	854	1,557	376	2,787	.48
September	3,205	228	810	195	1,233	.39
October	2,888	229	640	348	1,217	.42
November	2,267	190	624	267	1,081	.48
December	10,640	2,298	2,336	815	5,449	.51
1906.						
January	14,990	3,321	3,719	1,255	8,295	.55
February	5,116	664	1,643	220	2,527	.49
March	15,900	5,076	3,888	1,161	10,125	.64
April	22,440	4,538	4,464	2,013	11,015	.49
May	5,538	1,085	1,803	323	3,211	.58
June	7,007	770	2,895	413	4,078	.58
Mean ratio						[b] .537
Ratio of tributary drainage areas to drainage area above Point of Rocks						[b] .505

[a] Ice conditions. [b] September, 1903, to March, 1904, not included.

As a practical application of such comparisons as have been given above, the following may be of interest and value.

1. The observers' gage heights for the Point of Rocks station from January 1 to June 18, 1896, were corrected 0.7 by the hydrographer at that time; 0.4 was due to change of datum, but there are no data available to show why the correction for the remaining 0.3 was made. There has been a good deal of doubt in the mind of the writer whether it should have been made at all. The following comparisons strengthen this doubt still further. The mean daily discharge for the total period from January 1 to February 29 and from May 11 to June 17, 1896,[a] was found at all stations, except that an allowance of four days was made for flow from Cumberland and Spring-

[a] No record at Point of Rocks March 1 to May 10, 1896.

field to Point of Rocks. The estimate of the discharge at the Springfield station for May and June, during which there was no record was based on a comparison of Springfield and Millville estimates from May, 1895, to February, 1896, inclusive.

Discharge at various stations, January 1 to February 29 and May 11 to June 17, 1896.

Cumberland	second-feet..	882
Millville	do....	2,635
Springfield	do....	725
		4,242
Mean daily discharge at Point of Rocks, 0.7 correction being used	do....	5,910
Ratio of discharge at upper stations to that at Point of Rocks (0.7 correction)		.72
Ratio of drainage area at upper stations to that of Point of Rocks		.55

If the 0.3 correction had not been made the approximate mean daily discharge for the Point of Rocks station would have been 7,270 second-feet and the ratio of discharge of the upper stations to Point of Rocks would have been .58.

2. During 1897 the gage length was greatly in error, the final error recorded in January, 1898, being 1.8 feet. These gage heights were corrected by varying amounts for several periods. The amounts of the corrections were based on the gage-height distance that the several measurements of 1897 plotted above or below the rating curve. That this gave essentially correct results for the year is borne out by the following figures:

Discharge at various stations, December 28, 1896, to November 24, 1897.

Mean daily discharge at Cumberland December 28,[a] 1896, to November 20, 1897	second-feet..	1,086
Mean daily discharge at Millville January 1 to November 24, 1897	do....	3,058
Total		4,144
Mean daily discharge at Point of Rocks January 1 to November 24, 1897	do....	11,175
Ratio of discharge at upper stations to that at Point of Rocks		.37
Ratio of drainage area at upper stations to that at Point of Rocks		.40

The ratio of discharge is thus about 92 per cent of that of the drainage area. An allowance of 20,000 second-feet per day was made for omitted gage heights at Millville February 7, 8, and 9. There is every reason to believe that about 30,000 second-feet each day should also have been added for February 23 and 24, first, because it was known that the observer recorded gage heights above the top of the 10-foot gage on those days as 10.0 feet, and second, because of the flood at Point of Rocks the latter part of February, which shows a discrepancy of about this amount by a comparison of the relative drainage basins. If this is done the difference of the ratios is about 4

[a] Four days allowed for flow at Cumberland to reach Point of Rocks.

per cent. However, this still leaves a negative error of approximately 10 per cent, since the ratio of the discharges should be about 6 per cent greater than that of the drainage areas, according to the comparisons presented in the table (p. 31).

RAINFALL.

Probably no phenomenon has so important a bearing on the development of the country as rainfall. A study of this phenomenon, although an essential part of the hydrography of a district, is difficult, owing to the numerous and various conditions which regulate it. The fluctuations of both the yearly and monthly precipitation are great, and it is only by having a long series of records at many well-distributed points over an area that even a fair estimate of the conditions prevailing may be made.

The United States Weather Bureau has for a number of years regularly maintained rainfall stations well distributed throughout the United States. On the data collected at about 40 such stations, located either in or near the Potomac drainage basin, the accompanying discussion, tables, and map have been based.

The map (Pl. I, pocket) shows, by means of lines of equal rainfall, the average annual distribution of precipitation over the basin of the Potomac during the ten years from 1896 to 1905.

At many of the stations the data were missing for some portions of the period, and in order to complete the records for such stations the missing values were obtained by comparison with other near-by stations by the method of interpolation and extrapolation. This is made possible by the fact that the ratio between the precipitation at two adjacent stations remains fairly constant, although there is considerable variation in the actual amounts.

Since the prevailing wind directions are as important as the topographic surroundings in determining the precipitation at any given pair of stations, it seemed desirable to compute the ratios for many of the individual months as well as for the whole year. This proceeding involved more labor than would have been required to determine the ratios for whole years only; but it seems to have increased the accuracy of the results, especially in those cases where an interpolation of only a few months was required to fill out an otherwise complete series. This calculation of monthly ratios also makes it possible to obtain an approximately true annual ratio for two stations, one of which has many scattered monthly records, but few or no complete annual records. Another valuable feature of these ratios is that they make it possible to readily detect and eliminate errors in the rainfall records due to changes in gage exposure or to errors in recording or computing. This is illustrated by the ratios for the pair

of stations, Point of Rocks and Harpers Ferry, where an excessive ratio of 7.43 was found for October, 1895, as against an average ratio of 0.98 for that month.

In preparing the map of the Potomac basin the annual means as given on pages 34 to 40 were first plotted; then with the aid of several approximate means not given on the map, all points having the same precipitation were connected by meandering lines. Inspection shows that these lines, called "isohyets," follow closely the surface contours of the base map, while it will at once strike the reader that nearly all the stations are located in the valleys. Only a few stations in western Maryland and one station on the Blue Ridge of Virginia (Mount Weather) can be classed as mountain stations. Consequently we have at present no sufficient basis for calculating the rate of increase of precipitation with altitude in this basin. On this account also the course of the isohyet of 40 inches is, with few exceptions, to be regarded as hypothetical, although wherever possible it has been made to accord with such scanty and imperfect records as are obtainable.

Although the net of rainfall stations is not so finely meshed as is desirable for an area of the importance of the Potomac basin, yet the map shows distinctly that the rainfall of the lowlands decreases upstream from Washington. The lower-lying portions of the valley of the Shenandoah and its continuation, the Cumberland Valley of Maryland and Pennsylvania, were characterized by an annual fall of 35 to 40 inches of rain and melted snow. Generally the smaller amount is found along the Potomac itself, but the driest portion of the great valley lies in that section drained by Opequon Creek.

There seems to have been an exception to the rule just stated about the headwaters of South Branch of the Potomac. In that region there is a considerable area, inclosed by the isohyet of 35 inches, which has a rainfall of less than that amount. The two stations inclosed by the curve show amounts of 33.7 and 34.7 inches. This is apparently the dryest portion of the whole Potomac basin and, to judge from the neighboring portions of other river basins, it is but a portion of a relatively arid district which embraces the whole valley occupied by Bull Pasture River and South Branch of the Potomac.

Mean precipitation, in inches, at stations in drainage basin of Potomac River.

BACHMAN VALLEY, MD., ALTITUDE 880 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896–1900	2.77	5.92	5.46	2.80	6.26	3.67	4.01	3.92	3.19	3.01	5.16	3.36	59.56
1901–1905	4.65	4.17	6.30	4.21	3.57	6.87	7.76	7.35	4.93	5.26	a2.51	6.28	63.96
10-year mean	3.70	5.04	5.88	3.50	4.91	5.27	5.88	5.63	4.06	4.13	3.83	4.82	56.74

a 1 year interpolated, based on observations at Taneytown.

lean precipitation at stations in drainage basin of Potomac River—Continued.

HANCOCK, MD., ALTITUDE 455 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
00.....													[a]33.74
05.....	2.76	1.83	3.17	3.79	2.67	5.27	4.71	3.81	[b]2.16	[b]2.45	[b]1.48	[b]3.41	37.54
ar mean...													[a]35.64

HARNEY, MD., ALTITUDE 500 FEET.

00.....													[c]39.34
05.....	3.30	2.91	4.13	3.30	2.67	4.83	5.70	4.14	3.09	3.14	1.85	4.36	43.46
ar mean...													[c]41.40

HARPERS FERRY, W. VA., ALTITUDE 277 FEET.

00.....	2.64	4.18	3.60	1.66	4.63	3.12	3.74	3.80	2.75	2.91	3.58	2.76	39.37
05.....	3.19	1.95	4.27	3.75	3.42	4.50	5.14	3.21	3.16	2.76	1.89	3.89	41.13
ar mean...	2.91	3.06	3.93	2.70	4.02	3.81	4.44	3.50	2.95	2.83	2.73	3.82	40.25

LINCOLN, VA., ALTITUDE 500 FEET.

00.....													[d][33.11]
05.....	2.58	[e]2.34	[e]3.07	4.05	3.00	7.14	4.44	3.74	2.72	2.69	2.05	3.70	41.53
ar mean...													37.32

MARION, PA., ALTITUDE 640 FEET.

00.....													[f][37.50]
05.....													[a]40.89
ar mean...													39.19

MARTINSBURG, W. VA., ALTITUDE 435 FEET.

00.....	1.92	3.60	3.13	1.65	3.25	3.82	3.27	3.28	2.78	2.09	3.05	2.16	34.02
05.....	2.72	1.70	3.46	3.82	4.24	4.99	6.18	3.69	2.55	2.70	2.20	3.01	41.29
ar mean...	2.32	2.15	3.29	2.73	3.74	4.40	4.72	3.48	2.66	2.39	2.62	2.53	37.65

MOUNT ST. MARY COLLEGE, MD., ALTITUDE 720 FEET.

00.....	2.28	3.87	3.89	1.67	[g]4.31	3.35	4.66	4.42	3.01	3.06	3.95	2.57	41.07
05.....	3.65	2.48	4.47	4.36	3.17	5.12	4.74	[g]3.81	[g]2.85	3.38	2.00	4.02	44.06
ar mean...	2.96	3.17	4.18	3.01	3.74	4.23	4.70	4.11	2.93	3.72	2.97	3.29	42.56

NEW MARKET, MD., ALTITUDE 550 FEET.

00.....	2.62	4.48	[h]4.26	1.99	3.74	2.76	5.13	3.36	2.82	2.58	4.04	2.37	40.18
05.....	3.61	3.00	4.12	3.53	2.72	6.86	6.44	4.82	2.91	3.50	2.13	4.75	48.65
ar mean...	3.11	3.74	4.19	2.76	3.23	4.81	5.78	4.09	2.86	3.04	3.08	3.56	44.41

[a] 2 years interpolated, based on observations at Greenspring Furnace.
[b] 1 year interpolated, based on observations at Greenspring Furnace.
[c] 3 years interpolated, based on observations at Mount St Mary College.
[d] 5 years interpolated, based on observations at Frederick.
[e] 1 year interpolated, based on observations at Frederick.
[f] 5 years interpolated, based on observations at Greenspring Furnace.
[g] 1 year interpolated, based on observations at Harney.
[h] 1 year interpolated, based on observations at Frederick.

Mean precipitation at stations in drainage basin of Potomac River—Continued.

DEER PARK, MD., ALTITUDE 2,457 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896–1900	3.14	3.73	4.56	2.42	4.84	4.38	5.81	3.86	2.46	1.97	3.56	3.37	44.10
1901–1905	4.29	a3.16	b2.42	3.95	4.58	5.26	4.65	a3.14	1.74	2.66	a2.16	a3.67	41.70
10-year mean	3.71	3.44	3.47	3.18	4.71	4.82	5.23	3.50	2.10	2.31	2.86	3.52	42.90

DISTRIBUTING RESERVOIR, D. C., ALTITUDE 120 FEET.

1896–1900	2.26	4.26	2.84	1.64	3.44	2.71	3.32	3.83	2.82	2.00	2.44	c2.06	33.64
1901–1905	c3.05	c2.00	3.68	3.31	2.87	3.91	5.47	4.17	2.86	3.05	1.62	c4.40	40.42
10-year mean	2.65	3.13	3.17	1.65	3.10	3.31	4.39	4.00	2.84	2.52	2.03	3.23	37.03

FREDERICK, MD., ALTITUDE 345 FEET.

1896–1900	2.52	4.47	3.69	1.63	3.09	2.61	4.06	2.92	2.39	2.71	3.36	2.49	35.99
1901–1905	3.31	2.74	3.81	3.33	2.78	2.85	5.17	4.28	2.69	2.85	1.98	4.35	43.17
10-year mean	2.91	3.60	3.80	2.48	2.93	4.23	4.61	3.60	2.54	2.78	2.67	3.42	39.58

GETTYSBURG, PA.

1896–1900													d44.75
1891–1905													e46.76
10-year mean													45.75

GRANTSVILLE, MD., ALTITUDE 2,400 FEET.

1896–1900	3.21	4.30	5.00	2.53	4.05	3.84	6.57	3.59	2.85	2.56	4.16	2.88	45.59
1901–1905	3.51	2.98	3.83	3.79	3.96	4.24	3.50	3.32	2.12	2.63	1.78	4.11	39.81
10-year mean	3.36	3.64	4.41	3.16	4.00	4.05	5.03	3.45	2.48	2.59	2.97	3.49	42.70

GREAT FALLS, MD., ALTITUDE 150 FEET.

1896–1900	2.46	4.35	3.04	1.68	3.45	2.19	3.52	2.73	2.71	1.90	2.91	1.91	32.87
1901–1905	2.89	2.20	3.65	3.27	2.34	4.84	6.29	3.24	3.10	3.39	1.47	f4.61	41.32
10-year mean	2.67	3.27	3.34	2.47	2.84	3.51	4.90	2.98	2.90	2.64	2.19	3.26	37.09

GREENSPRING FURNACE, MD., ALTITUDE 500 FEET.

1896–1900	2.65	g3.80	3.43	1.63	4.12	2.85	3.52	3.39	2.69	2.21	3.11	2.16	35.71
1901–1905	2.98	2.27	3.18	3.32	3.13	4.61	5.04	3.87	2.37	2.53	1.82	3.64	38.81
10-year mean	2.81	3.03	3.30	2.47	3.62	3.73	4.28	3.63	2.53	2.37	2.46	2.90	37.26

HAGERSTOWN, MD., ALTITUDE 550 FEET.

1896–1900	2.27	4.28	4.13	1.31	h3.02	i3.54	j3.73	j3.85	i2.56	i2.37	3.25	2.21	36.52
1901–1905													k33.89
10-year mean													35.20

a 1 year interpolated, based on observations at Oakland.
b 2 years interpolated, based on observations at Oakland.
c 1 year interpolated, based on observations at Washington.
d 5 years interpolated, based on observations at Mount St. Mary College.
e 2 years interpolated, based on observations at Mount St. Mary College.
f 2 years interpolated, based on observations at Washington.
g 1 year interpolated, based on observations at Clear Spring.
h 1 year interpolated, based on observations at Chewsville and Sharpsburg.
i 3 years interpolated, based on observations at Chewsville and Sharpsburg.
j 2 years interpolated, based on observations at Chewsville and Sharpsburg.
k 4 years interpolated, based on observations at Chewsville and Sharpsburg.

Mean precipitation at stations in drainage basin of Potomac River—Continued.

HANCOCK, MD., ALTITUDE 455 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
00													[a] 33.74
05	2.76	1.83	3.17	3.79	2.67	5.27	4.71	3.81	[b] 2.16	[b] 2.45	[b] 1.48	[b] 3.41	37.54
ar mean													[a] 35.64

HARNEY, MD., ALTITUDE 500 FEET.

00													[c] 39.34
05	3.30	2.91	4.13	3.30	2.67	4.83	5.70	4.14	3.09	3.14	1.85	4.36	43.46
ar mean													[c] 41.40

HARPERS FERRY, W. VA., ALTITUDE 277 FEET.

00	2.64	4.18	3.60	1.66	4.63	3.12	3.74	3.80	2.75	2.91	3.58	2.76	39.37
05	3.19	1.95	4.27	3.75	3.42	4.50	5.14	3.21	3.16	2.76	1.89	3.89	41.13
ar mean	2.91	3.06	3.93	2.70	4.02	3.81	4.44	3.50	2.95	2.83	2.73	3.82	40.25

LINCOLN, VA., ALTITUDE 500 FEET.

00													[d] [33.11]
05	2.58	[e] 2.34	[e] 3.07	4.05	3.00	7.14	4.44	3.74	2.72	2.69	2.05	3.70	41.53
ar mean													37.32

MARION, PA., ALTITUDE 640 FEET.

00													[f] [37.50]
05													[a] 40.89
ar mean													39.19

MARTINSBURG, W. VA., ALTITUDE 435 FEET.

00	1.92	3.60	3.13	1.65	3.25	3.82	3.27	3.28	2.78	2.09	3.05	2.16	34.02
05	2.72	1.70	3.46	3.82	4.24	4.99	6.18	3.69	2.55	2.70	2.20	3.01	41.29
ar mean	2.32	2.15	3.29	2.73	3.74	4.40	4.72	3.48	2.66	2.39	2.62	2.53	37.65

MOUNT ST. MARY COLLEGE, MD., ALTITUDE 720 FEET.

00	2.28	3.87	3.89	1.67	[g] 4.31	3.35	4.66	4.42	3.01	3.00	3.95	2.57	41.07
05	3.65	2.48	4.47	4.36	3.17	5.12	4.74	[g] 3.81	[g] 2.85	3.38	2.00	4.02	44.06
ar mean	2.96	3.17	4.18	3.01	3.74	4.23	4.70	4.11	2.93	3.72	2.97	3.29	42.56

NEW MARKET, MD., ALTITUDE 550 FEET.

00	2.62	4.48	[h] 4.26	1.99	3.74	2.76	5.13	3.36	2.82	2.58	4.04	2.37	40.18
05	3.61	3.00	4.12	3.53	2.72	6.86	6.44	4.82	2.91	3.50	2.13	4.75	48.65
ar mean	3.11	3.74	4.19	2.76	3.23	4.81	5.78	4.09	2.86	3.04	3.08	3.56	44.41

[a] 2 years interpolated, based on observations at Greenspring Furnace.
[b] 1 year interpolated, based on observations at Greenspring Furnace.
[c] 3 years interpolated, based on observations at Mount St Mary College.
[d] 5 years interpolated, based on observations at Frederick.
[e] 1 year interpolated, based on observations at Frederick.
[f] 5 years interpolated, based on observations at Greenspring Furnace.
[g] 1 year interpolated, based on observations at Harney.
[h] 1 year interpolated, based on observations at Frederick.

Mean precipitation at stations in drainage basin of Potomac River—Continued.

OLD FIELD, W. VA., ALTITUDE 800 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896–1900	2.16	3.73	2.74	1.57	4.00	3.10	3.89	3.74	2.85	2.12	[a]2.19	[a]1.77	33.87
1901–1905													[b]33.64
10-year mean													33.75

POINT OF ROCKS, MD., ALTITUDE 235 (?) FEET.

1896–1900	2.39	3.66	3.55	1.79	3.98	3.38	3.82	3.30	2.98	2.54	2.97	2.11	36.69
1901–1905	2.68	2.15	3.27	3.43	3.57	4.91	4.48	3.69	2.31	[c]2.19	[d]1.46	[d]3.32	37.30
10-year mean	2.53	2.90	3.41	2.61	3.77	4.14	4.15	3.49	2.64	2.36	2.21	2.71	36.99

RECEIVING RESERVOIR, MD., ALTITUDE 160 FEET.

1896–1900	2.44	4.05	3.04	1.77	3.40	3.16	4.03	4.74	3.26	2.01	3.04	[e]2.13	37.05
1900–1905	[e]3.01	2.01	3.61	3.73	2.70	3.82	6.08	3.85	2.92	3.44	1.65	[e]4.76	41.61
10-year mean	2.72	3.03	3.32	2.75	3.05	3.49	5.05	4.29	3.09	2.72	2.34	3.44	39.33

RIVERTON, VA., ALTITUDE 493 FEET.

1896–1900													[f][32.50]
1901–1905									2.01	2.28	1.35	3.40	[g]32.58
10-year mean													32.54

ROMNEY, W. VA., ALTITUDE 824 FEET.

1896–1900													[h]35.40
1901–1905	2.29	[h]1.78	3.04	8.13	3.77	3.78	[h]4.34	[h]3.99	1.59	2.36	1.80	2.91	34.79
10-year mean													35.09

SHARPSBURG, MD., ALTITUDE 440 FEET.

1896–1900	2.56	3.83	3.26	[d]1.46	[d]3.94	3.22	3.78	3.16	[d]2.62	[d]2.29	3.07	2.16	35.37
1900–1905													[i]38.11
10-year mean													36.74

SHENANDOAH, VA., ALTITUDE 937 FEET.

1896–1900													[j][33.80]
1901–1905													[k]34.28
10-year mean													34.04

[a] 1 year interpolated, based on observations at Romney.
[b] 5 years interpolated, based on observations at Romney.
[c] 2 years interpolated, based on observations at Harpers Ferry.
[d] 1 year interpolated, based on observations at Harpers Ferry.
[e] 1 year interpolated, based on observations at Washington.
[f] 5 years interpolated, based on observations at Stephen City.
[g] 1 year interpolated, based on observations at Stephen City.
[h] 1 year interpolated, based on observations at Burlington.
[i] 3 years interpolated, based on observations at Harpers Ferry.
[j] 5 years interpolated, based on observations at Staunton.
[k] 1 year interpolated, based on observations at Staunton.

Mean precipitation at stations in drainage basin of Potomac River—Continued.

SOMERSET, PA., ALTITUDE 2,250 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896–1900	3.84	4.82	5.80	3.48	4.04	5.48	5.81	4.73	3.50	2.67	4.25	4.02	52.48
1901–1905	4.86	3.95	5.71	5.95	4.30	6.01	5.55	4.71	2.38	3.06	2.31	4.56	53.37
10-year mean	4.35	4.38	5.75	4.71	4.17	5.74	5.68	4.72	2.94	2.86	3.28	4.29	52.87

STAUNTON, VA., ALTITUDE 1,380 FEET.

1896–1900	2.56	3.32	3.93	1.95	4.30	3.59	3.62	3.83	3.71	3.57	2.53	1.90	38.85
1901–1905	2.69	2.95	3.16	3.95	4.09	5.45	4.32	3.55	2.62	1.99	1.68	3.53	40.02
10-year mean	2.62	3.13	3.54	2.95	4.19	4.52	3.97	3.69	3.16	2.78	2.10	2.71	39.43

STEPHENS CITY, VA., ALTITUDE 710 FEET.

1896–1900	2.39	4.16	3.69	1.57	4.22	3.90	4.01	4.11	2.99	3.17	2.51	2.41	39.17
1901–1905	.....	.....	3.64	.....	.....	.....	.....	.....	2.85	2.34	.....	.....	[a] 39.95
10-year mean	.....	.....	3.66	.....	.....	.....	.....	.....	2.92	2.75	.....	.....	39.56

SUNNYSIDE, MD., ALTITUDE 2,500 FEET.

1896–1900	4.73	5.78	6.46	3.49	5.68	5.69	7.04	4.63	3.99	3.01	5.44	4.42	60.38
1901–1905	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	[b] 51.32
10-year mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	55.85

TAKOMA PARK, MD., ALTITUDE 250 FEET.

1896–1900	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1901–1905	4.23	3.07	4.10	4.05	3.12	5.07	7.23	5.34	4.17	3.37	1.95	5.29	51.02
10-year mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TANEYTOWN, MD., ALTITUDE 490 FEET.

1896–1900	[c] 2.15	[c] 4.14	[c] 3.19	[c] 1.82	[c] 3.91	[c] 3.22	4.56	3.96	3.00	2.26	3.66	2.52	38.39
1901–1905	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	[d] 45.08
10-year mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	41.73

UPPER TRACT, W. VA., ALTITUDE 1,230 FEET.

1896–1900	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	[e] [35.62]
1901–1905	2.22	1.87	2.67	2.95	3.82	[c] 4.89	3.96	4.16	1.87	1.67	1.64	3.14	34.69
8-year mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35.15

WASHINGTON, D. C., ALTITUDE 112 FEET.

1896–1900	2.76	4.97	3.67	1.94	3.87	3.94	3.93	4.16	3.27	2.33	2.58	2.28	39.73
1901–1905	3.40	2.97	3.69	3.70	2.95	4.39	5.81	4.64	3.06	3.37	1.96	4.69	44.67
10-year mean	3.08	3.97	3.68	2.82	3.41	4.16	4.87	4.40	3.16	2.85	2.27	3.48	42.20

[a] 1 year interpolated, based on observations at Riverton.
[b] 3 years interpolated, based on observations at Deer Park and Oakland.
[c] 1 year interpolated, based on observations at Bachman Valley.
[d] 3 years interpolated, based on observations at Bachman Valley.
[e] Mean for 1898–1900.

Mean precipitation at stations in drainage basin of Potomac River—Continued.

WESTERNPORT, MD., ALTITUDE 1,000 FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896–1900	2.35	3.10	3.52	2.41	4.08	3.51	4.10	3.10	2.81	2.35	2.98	1.70	36.46
1901–1905	2.28	1.93	2.92	3.06	3.68	4.76	4.71	3.14	2.33	1.92	1.17	2.89	34.51
10-year mean	2.31	2.51	3.22	2.74	3.88	4.13	4.40	3.12	2.57	2.13	2.07	2.29	35.41

WOODSTOCK, VA., ALTITUDE 927 FEET.

1896–1900									3.12	2.92	2.11	1.80	[a]35.15
1901–1905	2.59	1.77	2.99	3.25	3.57	5.71	3.03	4.04	2.23	2.06	1.41	3.00	35.67
10-year mean									2.67	2.49	1.76	2.40	35.41

[a] 1 year interpolated, based on observations at Stephens City.

COMPARISON OF RAINFALL AND RUN-OFF.

At eight river-measurement stations in the Potomac drainage basin the records of run-off were of sufficient extent for the comparison of rainfall and run-off. These stations are as follows:

Potomac at Point of Rocks, Md.
Monocacy near Frederick, Md.
Antietam Creek, near Sharpsburg, Md.
South Branch of Potomac near Springfield, W. Va.
North Branch of Potomac near Piedmont, W. Va.
South Branch of Shenandoah near Front Royal, Va.
North Branch of Shenandoah near Riverton, Va.
Shenandoah at Millville, W. Va.

The rainfall stations in the areas above these stations are so distributed as to represent fairly well the conditions over the various areas. It has been assumed that for any area the mean rainfall for a given month is the mean of the monthly rainfall at the various stations in that area. Based on this assumption, the monthly and yearly rainfall for the years for which run-off records are available has been determined. These values are included in the tables of mean monthly run-off given for each gaging-station in other parts of this report. When these monthly rainfall tables were prepared some of the data given on pages 34–40 were not available.

From the monthly rainfall and the monthly run-off the run-off in per cent of rainfall has been determined and also the loss of rainfall.

In the comparison of run-off and rainfall the following facts must be kept in mind. First, run-off is a resultant quantity, being the amount of water left after evaporation, vegetation, seepage, etc., in the area have been satisfied; second, a rain gage shows only the rain that falls on a few square inches of surface. There should be many rain gages in order to ascertain the average precipitation over a watershed, and, as maximum precipitation often occurs in comparatively small areas, it may not be recorded. Third, ground and surface storage modify the relation between precipitation and run-off. The run-off for a month in early spring may be much larger than the precipitation for that month, on account of melting snow that falls during the winter months. Again, in the early fall, when the ground water is low, a small rainfall yields a much smaller run-off than it would during the spring, when the ground is nearly saturated with water. Fourth, heavy rainfall frequently occurs at the end of the month, and as the run-off data are computed for the calendar months, the results from such rainfall may appear in the following month's record. Fifth, data are not available relative to snow storage, which produces the high percentages of run-off usually obtained for the late winter and early spring. To account fully for this storage, a sample of snow extending from top to bottom should be melted at the end of each month, in order to determine the total amount of water stored on the ground. The quantity available for run-off during the following month would be the amount thus determined plus the precipitation during the following month minus the amount left in snow storage at the end of that month plus or minus the change in ground water. These and other causes make the monthly ratios of run-off to rainfall appear very erratic. A month is too short a period for the comparison of these quantities. A year is a better period, but not entirely satisfactory, especially if the calendar year is taken, as the snow and ground-water storage are not in the same conditions at the end of each year.

Notwithstanding the above facts, the rainfall and stream data and the comparison between the two are very consistent from year to year and from station to station, and are of great interest both for comparative purposes and to show the general conditions existing in the drainage.

GAGING STATIONS.

In the following table are listed the stations in the Potomac basin at which stream measurements have been made by the United States Geological Survey:

Gaging stations of the United States Geological Survey in the Potomac basin.

Station.	Period of observations.
Savage River at Bloomington, Md.	May 3, 1905, to July 15, 1906.
North Branch of Potomac River at Piedmont, W. Va.	June 27, 1899, to July 15, 1906.
Georges Creek at Westernport, Md.	May 4, 1905, to July 15, 1906.
Wills Creek at Cumberland, Md.	May 6, 1905, to July 14, 1906.
North Branch of Potomac River at Cumberland, Md.	June 11, 1894, to Nov. 20, 1897.
South Branch of Potomac River near Springfield, W. Va.	June 3, 1894, to Oct. 20, 1894; Apr. 11, 1895, to Feb. 29, 1896; June 26, 1899, to Feb. 24, 1902; Aug. 28, 1905, to July 14, 1906.
Potomac River at Great Cacapon, W. Va.[a]	
Tuscarora Creek at Martinsburg, W. Va.	May 8 to Dec. 30, 1905
Opequon Creek near Martinsburg, W. Va.	May 9 to June 4, 1905; Oct. 8, 1905, to July 15, 1906.
Antietam Creek near Sharpsburg, Md.	July 1, 1897, to Aug. 25, 1905.
South River at Basic, Va.	June 29, 1905, to July 15, 1906.
South River at Port Republic, Va.	Aug. 6, 1895, to Apr. 1, 1899.
Cooks Creek at Mount Crawford, Va.	July 1, 1905, to July 15, 1906.
Lewis Creek at Staunton, Va.	Do
North River at Port Republic, Va.	Aug. 6, 1895, to Apr. 1, 1899.
Elk Run at Elkton, Va.	June 28, 1905, to July 15, 1906.
Hawksbill Creek near Luray, Va.	June 27, 1905, to July 15, 1906.
South Branch of Shenandoah River near Front Royal, Va.	June 26, 1899, to July 16, 1906.
Passage Creek at Buckton, Va.	Oct. 26, 1905, to July 15, 1906.
North Branch of Shenandoah River near Riverton, Va.	June 26, 1899, to July 14, 1906.
Shenandoah River at Millville, W. Va.	Since Apr. 15, 1895.
Potomac River at Point of Rocks, Md.	Since Feb. 17, 1895.
Monocacy River near Frederick, Md.	Since Aug. 4, 1896.
Rock Creek at Lyon's mill, Washington, D. C.	Aug. 18, 1892, to Nov. 30, 1894.
Rock Creek at Zoological Park, D. C.	Jan. 18, 1897, to Nov. 10, 1900.

[a] Gage-height records were obtained from June 21, 1894, to March 7, 1896, but are not republished on account of their unreliability.

Daily gage-height records are at present maintained by the Weather Bureau in the Potomac drainage basin at Cumberland, Md.; Riverton, Va., and Harpers Ferry, W. Va. General information and tables of gage heights at these stations can be found in the Weather Bureau Report of Daily River Stages of the Principal Rivers of the United States.

The Cumberland station on North Branch of Potomac River was established September 1, 1901, at the dam just below the mouth of Wills Creek. The range of stage since the date of establishment has been from 0 to 11.5 feet. The danger line is at 8 feet. The datums of the Weather Bureau and Geological Survey gages have not been connected by level at this point. It is not considered advisable to attempt to obtain additional estimates at Cumberland based on the Weather Bureau records, because no discharge measurements have been made there since 1898.

The Riverton station on Shenandoah River was established September 1, 1901, at the Norfolk and Western Railway bridge below the junction of North and South branches. Gage heights were also obtained at this point during 1892 to 1894. The highest water was

feet September 30 and October 1, 1870; the lowest since 1900 was 1.7 feet. The danger line is at 22 feet.

The Harpers Ferry station on Potomac River was established in 82 at the Baltimore and Ohio Railroad bridge. November 1, 1901, e gage datum was lowered 2.00 feet. The highest water was 36 t, June 1, 1889; the high water of November, 1877, was 29.2 feet; e lowest on various dates —3 feet. The danger line is at 18 feet. evations have been reduced to new datum.

Records were also kept of the elevation of the water surface at gh tide at Long Bridge, Washington, D. C., from June 1, 1891, to pril 15, 1893. For flood stages see page 181. The danger point 8 feet on the gage, or about 7 feet above mean sea level. Daily ge heights at Great Falls have likewise been published from 1890 1892 inclusive.

NORTH BRANCH OF POTOMAC RIVER BASIN.

GENERAL DESCRIPTION.

The general features of the basin of North Branch of Potomac ver are described on page 213. The country drained comprises ep mountain slopes and narrow valleys. The run-off is rapid and ctuations in flow are great. The fall of the stream both above and ow Cumberland is large. Facilities for dams are excellent. The utaries of North Branch are comparatively small and the fall many of them is rapid.

SAVAGE RIVER AT BLOOMINGTON, MD.

Savage River rises on Bog and Little Savage mountains, in the theastern part of Garrett County, Md., and flows in a general thwesterly direction for about 20 miles, then turns to the south- t, and enters North Branch of Potomac River near Bloomington. e drainage area is practically uninhabited and the watershed is en over to lumbering. The river receives the waters of a num- of small runs. The gaging station on Savage River was estab- ed May 3, 1905, and was discontinued July 16, 1906. It is located a highway bridge about 800 feet above the junction of Savage ver with North Branch of the Potomac.

The channel is straight for 200 feet above and below the station. e current is swift. The right bank is low and clean and has an erflow channel at high water. The left bank is high and does t overflow. The bed of the stream is rocky, very irregular, and rmanent. There is but one channel at low and ordinary stages; ring high-water stages there are two channels.

Discharge measurements were made from the downstream side of e steel bridge to which the gage is fastened. The initial point for ndings is the center of the bridge pier at the left abutment, down- eam side.

A standard chain gage is attached to the downstream side of the bridge near the left abutment. The length of the chain from the end of the weight to the marker is 21.15 feet. The gage was read twice each day by F. S. Cline. Bench mark No. 1 is a chiseled cross on the downstream corner of the left abutment. Its elevation is 16.49 feet above gage datum. Bench mark No. 4 is the top of the pulley wheel of the gage. Its elevation was 20.82 feet above gage datum March 16, 1906.

Estimates are considered to be within 5 per cent of the true discharge for stages above 30 second-feet. Below this limit the probable error may be somewhat greater. The estimates do not include the flow in the 10-inch pipe which carries the Piedmont water supply. This pipe rests upon the river bottom at the bridge and in low water carries an appreciable percentage of the total flow of the river. Ice conditions did not affect the flow at this station during the winter of 1905–6.

Discharge measurements of Savage River at Bloomington, Md.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
April 18	2.90	89	March 16	2.95	9[illegible]
May 4	2.68	72	April 10	5.60	1,13[illegible]
June 7	2.88	81	Do	5.40	1,02[illegible]
July 17	2.47	37	April 11	4.79	68[illegible]
November 7	2.59	66	May 28	3.25	141

Daily gage height, in feet, of Savage River at Bloomington, Md.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1						2.8	2.32	2.6	2.18	1.98	2.82	3.5[illegible]
2						2.72	3.3	2.42	2.2	2.12	2.78	3.92
3					2.7	2.62	2.92	2.22	2.13	2.08	2.62	3.72
4					2.7	2.52	2.82	2.12	2	2.15	2.55	4.58
5					2.62	2.52	2.72	2.05	9	2.05	2.5	4.28
6					2.62	2.42	2.48	2.1	88	1.9	2.58	3.7
7					2.62	2.97	3.62	1.92	85	1.9	2.58	3.52
8					2.58	3.42	4.32	1.85	7	1.8	2.48	3.35
9					2.5	3.22	3.75	1.9	9	1.85	2.52	3.18
10					2.45	2.92	3.52	1.85	78	1.78	2.42	3.35
11					2.4	3.93	3.38	1.85	4.48	2.22	2.4	2.88
12					2.78	4.55	3.1	2.25	3.85	2.75	2.35	2.88
13					2.7	4.25	2.92	2.08	3.4	2.48	2.28	2.82
14					3.0	3.75	2.88	1.95	3.08	2.42	2.25	2.72
15					4.15	3.4	2.72	2.05	2.75	2.32	2.22	2.62
16					3.52	3.18	2.52	2.45	2.58	2.22	2.42	2.45
17					3.75	2.92	2.4	2.22	2.52	2.18	2.32	2.82
18					3.65	2.78	2.32	2.19	2.45	2.02	2.25	2.65
19					3.48	2.68	2.28	2.15	2.42	2.1	2.22	2.52
20					3.25	2.72	2.4	2.05	2.28	4.42	2.2	2.65
21					3.1	2.78	2.28	2.05	2.18	3.75	2.08	3.75
22					2.92	2.6	2.22	1.95	2.12	3.28	1.92	4.52
23					2.78	2.52	2.6	1.82	2.05	3.05	2.05	4.48
24					2.62	2.85	2.35	1.85	2.3	2.92	2.22	4.25
25					2.6	2.82	2.18	3.05	1.9	2.85	2.28	3.9
26					2.6	2.68	2.18	3.55	1.9	3.55	2.2	3.7
27					2.6	2.8	2.02	2.92	1.95	3.6	2.12	3.48
28					2.48	2.58	1.9	2.68	1.9	3.48	2.1	2.78
29					2.4	2.48	2.15	2.62	1.9	3.35	3.42	3.4
30					2.4	2.32	2.62	2.48	1.85	2.7	4.2	2.[illegible]
31					2.5		2.82	2.32		2.92		2.15

Daily gage height, in feet, of Savage River at Bloomington, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.												
	2.8	2.75	2 5ɜ	5.32	3.22	3.35	2.48					
	2.75	2.55	2.43	4.82	3.18	3.28	2.38					
	3.05	2.65	2.7ɜ	4.98	3.32	2.95	2.28					
	4.28	3.03	4.45	5.22	3.22	2.75	2.2					
	4.52	2.75	3.83	5.88	3.0	2.75	2.12					
	4.15	2.6	3.	5.92	3.0	3.35	1.98					
	3.85	2.67	3.37	4.88	2.92	4.62	1.88					
	3.6	2.6	3.25	4.48	2.82	5.15	1.88					
	3.3	2.53	3.17	4.42	2.82	4.05	1.88					
	3.12	2.6	3.15	5.95	2.8	3.6	1.88					
	3.18	2.37	2.97	4.9	2.72	3.32	1.92					
	3.2	2.47	3.05	4.35	2.68	3.05	1.88					
	2.75	2.5	2.87	3.95	2.58	2.88	1.88					
	3.18	2.47	2.93	3.8	2.52	3.05	1.92					
	3.02	2.37	3.2	4.78	2.52	2.85	1.78					
	3.25	2.4	2.93	4.6	2.48	2.65						
	3.52	2.47	2.88	4.3	2.38	2.55						
	3.6	2.27	2.74	4.05	2.32	2.38						
	4.02	2.33	2.78	3.75	2.42	2.3						
	4.0	2.33	2.95	3.55	2.32	2.52						
	4.15	2.47	2.9	3.52	2.3	2.98						
	4.32	2.63	2.98	3.4	2.3	2.82						
	7.08	2.63	2.75	3.48	2.25	2.78						
	5.5	2.35	3.18	3.4	2.2	2.78						
	4.55	2.47	3.05	3.52	2.2	2.62						
	4.1	2.37	3.05	3.62	2.2	2.65						
	3.6	2.23	4.85	3.65	2.42	2.78						
	3.52	2.25	6.5	3.58	3.4	2.75						
	3.48	.....	6.0	3.48	3.35	2.55						
	3.2	.....	7.15	3.35	2.95	2.42						
	3.18	.....	6.05	.....	2.82	.....						

ating table for Savage River at Bloomington, Md., from May 3, 1905, to July 15, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.70	8	2.90	84	4.00	344	5.20	912
1.80	10	3.00	98	4.10	380	5.40	1,030
1.90	12	3.10	114	4.20	418	5.60	1,150
2.00	15	3.20	132	4.30	458	5.80	1,280
2.10	19	3.30	152	4.40	500	6.00	1,415
2.20	23	3.40	174	4.50	544	6.20	1,555
2.30	28	3.50	197	4.60	591	6.40	1,695
2.40	34	3.60	222	4.70	640	6.60	1,840
2.50	41	3.70	249	4.80	691	6.80	1,990
2.60	50	3.80	278	4.90	744	7.00	2,140
2.70	60	3.90	310	5.00	799	7.20	2,300
2.80	71						

[a] This table is strictly applicable only for open-channel conditions. It is based upon eight discharge measurements made during 1905 and 1906. It is well defined between gage heights 2.4 feet and 5.6 feet.

Estimated monthly discharge of Savage River at Bloomington, Md.

[Drainage area, 120 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
May 3–31	399	34	97.8	0.815	0.679
June	568	29	118	.983	1.10
July	466	12	85.0	.708	.816
August	210	10	34.0	.283	.326
September	535	8	56.0	.467	.521
October	509	10	82.1	.684	.789
November	418	13	51.1	.426	.475
December	924	21	220	1.83	2.11
1906.					
January	2,204	66	330	2.75	3.17
February	103	24	43.8	.365	.380
March	2,260	36	348	2.90	3.34
April	1,380	163	521	4.34	4.84
May	174	23	69.9	.582	.671
June	884	28	138	1.15	1.28
July 1–15	40	10	17.8	.148	.062

NORTH BRANCH OF POTOMAC RIVER AT PIEDMONT, W. VA.

This gaging station was established June 27, 1899, by E. G. Paul, and was discontinued July 16, 1906. It is located at the iron highway bridge connecting Luke, Md., with Piedmont, W. Va.

The channel is straight for 1,200 feet above and 600 feet below the station. The current has a moderate velocity. The right bank is high and rocky and does not overflow. The left bank is low and liable to overflow, but all water passes beneath the bridge. The bed of the stream is composed of gravel and cobblestones, overlain in the left channel and in part of the right channel by refuse from pulp mills above the bridge. It is free from vegetation. Discharge measurements were made from the downstream side of the bridge to which the gage is attached. The initial point for soundings is the face of the pier on the right bank.

The standard chain gage is attached to the hand rail on the lower side of the bridge in the second span from the right end. The length of the chain from the end of the weight to the marker is 38.8 feet. The gage was read twice each day by Charles H. Beck. The bench mark is the top of a small shoulder in the face of the sandstone ledge which forms the right abutment of the bridge. It is about 3 feet above the ground and 10 feet downstream from the bridge. The point is indicated by an arrow cut in the vertical face of the ledge. Its elevation is 20.40 feet above gage datum.

The plotting of the discharge measurements made during 1899 to 1906 indicates that the channel has been gradually filling in at the control below the gaging section, and also to some extent at the gaging section itself, thus causing a gradually diminishing discharge for a given gage height. This apparently is due to refuse discharged into

ver from pulp mills immediately above the bridge. The amount use affecting the flow does not increase at a constant rate, and ies of high water part of it may be washed away. Owing to these ging conditions of flow all estimates at this station are somewhat tain, there being a varying error of from 5 to 20 per cent. The r percentages of error occur at low-gage heights, especially during ds when no measurements were made. The three rating curves to 1906 have been united at about gage height 4.5 feet. This is trictly correct, but the percentage of error involved is relatively . Ice conditions at this station probably do not greatly affect ischarge. No corrections were made in estimates for ice periods. ıates for the period from June 27, 1899, to December 31, 1903, ously published have been revised. Estimates for 1904 and as published in the 1905 report, have not been changed.

summary of the records furnishes the following results: Maxi- discharge for twenty-four hours, 13,450 second-feet; minimum arge for twenty-four hours, 6 second-feet; mean annual dis- ge for six years, 687 second-feet; mean annual rainfall for seven , 38.66 inches.

ischarge measurements of North Branch of Potomac River at Piedmont, W. Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1899.	*Feet.*	*Second-feet.*		*Feet.*	*Second-feet.*
27	3.00	350	September 9	1.99	14.7
			September 28	1.99	20
1900.					
y 22	3.75	735	1905.		
	4.40	1,249	March 9	6.70	4,516
er 12	1.80	34	March 10	7.47	6,047
			March 29	4.25	1,096
1901.			April 18	3.46	416
	2.90	275	April 24	3.63	526
er 7	2.10	39	May 4	3.22	326
			June 7	3.44	441
1902.			July 17	3.15	280
19	2.14	50	November 7	3.38	439
1903.			1906.		
31	2.80	208	March 16	3.51	412
			March 30	7.15	5,819
1904.			April 11	5.64	2,589
	2.80	116	May 28	3.49	391

[a] Measurement unreliable, owing to defective meter.

Daily gage height, in feet, of North Branch of Potomac River at Piedmont, W. Va.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	D
1899.												
1							3.15	2.5	2.2	2.2	3.75	2
2							2.9	2.35	2.2	2.2	3.9	2
3							2.8	2.25	2.1	2.15	3.05	2
4							2.7	2.4	2.0	2.1	2.8	2
5							2.65	2.4	2.3	2.1	2.8	2
6							2.7	2.4	2.2	2.1	2.55	2
7							2.8	2.55	2.15	2.2	2.5	2
8							2.7	2.45	2.1	2.1	2.4	2
9							2.7	2.3	2.2	2.15	2.4	2
10							2.7	2.25	2.3	2.1	2.4	2
11							2.65	2.1	2.95	2.1	2.4	2
12							2.5	2.15	3.4	2.2	2.4	3
13							2.4	2.1	2.75	2.1	2.3	4
14							2.85	2.1	2.45	2.1	2.3	3
15							2.85	2.1	2.35	2.0	2.3	3
16							2.5	2.0	2.3	2.2	2.3	3
17							2.7	2.0	2.3	2.1	2.3	3
18							2.9	2.0	2.15	2.1	2.2	3
19							2.65	2.0	2.1	2.1	2.4	3
20							2.5	2.0	2.45	2.1	3.35	3
21							2.4	2.0	2.9	2.1	3.0	3
22							2.35	1.95	2.65	2.0	2.8	3
23							2.3	1.9	2.4	2.0	2.85	3
24							2.3	1.9	2.4	2.1	3.3	3
25							2.3	1.9	2.25	2.1	3.2	3
26							2.2	1.9	2.2	2.1	3.0	2
27						3.0	2.15	2.1	2.3	2.1	2.8	2
28						2.9	2.5	3.0	2.55	2.1	2.8	2
29						2.85	2.35	2.9	2.4	2.2	2.7	2
30						3.5	2.3	2.55	2.25	2.15	2.6	2
31							2.45	2.35		2.15		2
1900.[a]												
1	2.7	3.0	3.55	4.6	3.15	3.3	3.0	2.95	2.1	2.85	2.1	3
2	2.7	3.05	4.5	4.8	3.1	3.25	2.85	2.75	2.0	2.45	2.1	3
3	2.7	3.1	4.1	4.65	3.1	3.25	2.7	2.65	2.0	2.2	2.25	3
4	2.7	3.1	4.0	4.5	3.1	3.05	2.7	2.6	2.0	2.1	2.65	5
5	2.7	3.35	4.3	4.25	3.0	2.9	2.7	2.4	2.0	2.2	2.7	5
6	2.8	3.6	4.25	4.15	2.95	2.85	2.6	2.3	1.95	2.2	2.5	4
7	2.9	3.7	5.8	4.15	2.9	2.85	2.7	2.3	1.9	2.2	2.4	4
8	3.0	[b]5.3	5.0	4.3	2.9	3.15	3.0	2.2	1.9	2.1	2.3	4
9	3.3	5.4	4.55	4.2	2.95	3.15	2.85	2.2	1.9	2.05	2.4	3
10	3.5	4.65	4.4	3.95	3.2	2.95	2.7	2.1	1.9	2.0	2.5	3
11	3.5	4.4	4.3	3.75	3.05	2.8	2.6	2.05	1.8	2.0	2.5	3
12	[b]4.7	4.05	4.15	3.7	3.0	2.7	2.45	2.0	1.8	2.0	2.6	3
13	4.25	5.9	4.1	3.65	2.9	2.7	2.6	2.1	1.8	2.0	2.6	3
14	3.9	5.5	4.1	3.55	2.8	3.15	2.65	2.0	1.8	3.05	2.5	3
15	3.9	4.8	4.0	3.4	2.8	3.2	2.55	2.0	1.8	3.2	2.5	3
16	3.9	4.35	3.8	3.4	2.8	3.95	2.35	2.1	1.8	2.65	2.4	3
17	4.4	4.15	3.7	3.4	2.8	7.55	2.3	2.4	1.9	2.5	2.4	3
18	4.1	4.05	3.7	3.55	2.7	5.85	2.25	2.25	1.9	2.4	2.4	3
19	4.15	3.7	4.0	3.75	3.4	4.95	2.35	2.25	1.9	2.25	2.4	3
20	5.8	3.65	5.95	3.65	3.95	4.45	2.9	2.45	1.9	2.2	2.5	3
21	5.7	3.6	5.35	3.5	3.55	3.95	2.75	2.2	1.8	2.1	2.6	3
22	4.75	3.75	4.75	3.5	3.35	3.65	2.55	2.2	1.8	2.1	3.2	3
23	4.35	4.0	4.6	3.65	3.2	3.5	2.45	2.65	1.8	2.15	3.0	3
24	4.1	3.7	4.6	3.85	3.15	3.35	2.4	2.45	1.8	2.35	2.9	3
25	3.95	3.6	4.5	3.65	3.05	3.25	3.2	2.4	1.8	2.8	3.35	3
26	3.8	3.4	4.25	3.5	3.0	3.25	4.05	2.45	1.8	2.5	7.95	
27	3.55	3.4	4.35	3.4	2.95	3.05	4.4	2.45	1.85	2.35	5.2	
28	3.4	3.4	4.15	3.4	2.9	2.9	3.2	2.3	1.9	2.3	4.45	
29	3.3	.....	4.0	3.3	3.3	3.55	3.0	2.2	1.95	2.2	4.05	
30	3.2	.....	4.75	3.25	3.25	3.15	3.0	2.15	2.7	2.2	3.75	
31	3.1	.....	4.6	.....	3.1	.....	3.25	2.1	.....	2.2	.....	

[a] Slight ice conditions during January and February, 1900.
[b] Ice passed down the river January 12 and February 8, 1900.

y gage height, in feet, of North Branch of Potomac River at Piedmont, W. Va.— Continued.

Day.	an.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.[a]												
	3.4	3.3	2.85	3.8	4.0	4.25	3.35	2.5	3.2	2.55	2.1	2.5
	3.2	3.2	3.0	3.65	3.9	4.4	3.15	2.5	3.0	2.4	2.1	2.7
	2.95	3.2	4.0	4.0	3.8	4.1	3.0	2.4	2.9	2.4	2.1	5.6
	2.95	3.2	5.2	4.0	3.75	3.9	3.0	2.4	2.8	2.5	2.1	5.2
	3.15	3.3	4.6	4.45	3.6	3.7	2.9	2.3	2.7	2.4	2.1	4.2
	3.1	3.3	3.85	6.55	3.4	3.6	2.8	2.4	2.6	2.4	2.1	3.5
	3.0	3.2	3.8	6.3	3.4	4.0	2.8	3.35	2.55	2.35	2.1	3.5
	2.9	3.2	3.8	5.65	3.3	4.0	2.8	2.85	2.5	2.25	2.1	3.5
	3.0	3.1	4.7	5.0	5.75	3.8	2.7	2.6	2.5	2.2	2.0	3.55
	3.0	3.1	6.2	4.65	7.55	3.55	2.6	2.5	2.4	2.2	2.0	5.7
	4.0	3.2	6.9	4.5	5.9	3.35	2.45	2.45	2.6	2.2	2.0	4.55
	5.75	3.1	5.65	4.3	5.25	3.15	2.4	2.35	2.7	2.2	2.05	4.05
	4.65	3.0	5.15	4.2	4.9	4.25	2.6	2.3	2.6	2.25	2.1	3.8
	4.15	3.0	5.2	4.65	4.6	3.95	3.5	2.45	2.6	2.3	2.2	4.3
	4.1	2.9	4.75	5.25	4.25	4.3	3.8	2.3	2.5	2.3	2.3	8.15
	4.0	3.0	4.4	5.6	4.1	4.9	5.3	2.3	2.45	2.25	2.2	5.55
	3.9	3.1	4.1	5.7	3.95	4.95	5.1	2.45	2.55	2.2	2.1	4.65
	3.55	3.15	4.05	5.4	3.8	4.7	4.25	3.15	2.6	2.2	2.1	4.2
	3.25	3.6	4.05	4.95	3.7	4.3	4.15	3.1	2.6	2.1	2.1	3.8
	3.35	3.4	4.15	7.6	3.75	4.05	3.55	3.35	2.5	2.1	2.1	3.4
	3.5	3.2	4.55	7.55	3.7	3.75	3.2	3.6	2.4	2.1	2.1	3.4
	3.9	3.1	4.35	6.35	4.55	3.55	3.1	3.35	2.4	2.1	2.1	3.4
	3.7	3.0	4.2	5.85	5.6	3.35	2.95	3.35	2.3	2.1	2.15	3.55
	3.6	2.85	4.05	5.65	4.65	3.2	2.9	4.95	2.3	2.1	2.7	3.5
	4.0	2.95	4.15	5.35	4.3	3.1	2.8	4.8	2.3	2.1	3.0	[b]4.7
	3.7	2.95	4.15	5.05	4.55	3.2	2.7	3.9	2.2	2.1	2.85	4.3
	3.7	2.9	4.55	4.65	6.25	3.95	2.7	3.55	2.2	2.1	2.65	4.95
	3.55	2.85	4.25	4.35	6.15	4.8	2.7	3.65	2.25	2.1	2.55	4.25
	3.35	.....	4.05	4.2	5.9	4.4	2.6	3.45	2.9	2.1	2.45	6.65
	3.5	.....	3.9	4.1	5.55	3.7	2.5	3.15	2.9	2.1	2.6	5.8
	3.35	.....	3.75	.....	5.05	.....	2.5	3.0	.....	2.1	.....	4.8
1902.[c]												
	4.45	3.8	8.05	4.9	3.55	3.3	4.75	2.85	1.9	3.3	2.55	4.0
	4.0	3.6	7.1	4.65	3.4	3.2	3.8	2.7	1.9	3.35	2.5	3.75
	4.3	3.5	6.2	4.4	3.7	3.1	3.35	2.6	1.9	2.85	2.5	5.25
	3.8	3.2	5.4	4.7	3.7	3.0	3.2	2.5	2.0	2.7	2.4	4.55
	3.55	3.4	4.95	5.05	3.55	3.0	3.1	2.5	2.2	2.9	2.4	4.3
	3.6	3.5	4.5	5.95	3.45	2.85	2.95	2.5	2.35	2.9	2.4	3.9
	3.6	3.5	4.2	6.2	3.5	2.8	2.8	2.5	2.2	2.85	2.4	3.8
	3.6	3.4	4.2	6.45	3.4	2.85	3.05	2.4	2.1	2.6	2.5	3.75
	3.45	3.3	4.65	5.85	3.3	2.95	3.2	2.4	2.0	2.5	2.5	3.5
	3.45	3.2	4.95	5.7	3.2	2.85	2.95	2.45	2.0	2.4	2.5	3.45
	3.4	3.15	5.65	6.2	3.4	2.7	3.2	2.5	2.0	2.4	2.5	5.55
	3.3	3.15	6.85	7.05	3.25	2.7	3.05	2.4	2.0	3.25	2.5	6.45
	3.1	3.1	8.1	6.25	3.2	2.6	2.8	2.35	1.9	3.7	2.5	6.0
	3.2	3.05	6.6	5.8	3.15	3.1	2.7	2.3	1.9	3.35	2.5	5.8
	3.2	3.1	5.85	5.55	3.1	2.9	2.6	2.25	1.9	3.15	2.4	5.0
	3.1	3.0	5.85	5.25	3.05	2.8	2.5	2.2	1.9	2.95	2.4	7.6
	3.05	3.0	6.75	5.1	3.0	2.7	2.45	2.2	1.9	2.7	2.4	6.45
	2.9	3.0	5.65	4.95	3.0	2.6	2.4	2.2	1.9	2.7	2.5	5.45
	3.0	3.0	4.95	4.55	2.9	2.5	2.4	2.15	1.9	2.7	2.5	4.9
	2.9	2.85	4.6	4.4	3.45	2.5	2.55	2.1	1.9	2.6	2.5	4.7
	2.9	2.8	4.45	4.25	3.75	2.6	2.6	2.15	1.9	2.5	2.5	5.0
	2.9	2.8	4.5	4.15	3.45	2.9	2.5	2.5	2.0	2.4	2.5	5.9
	2.9	3.0	4.5	4.25	3.4	2.7	2.4	2.4	2.0	2.4	2.5	5.15
	3.0	3.05	4.5	4.15	3.3	2.5	2.4	2.3	2.0	2.4	2.5	4.7
	3.0	[d]3.35	4.45	3.8	3.3	2.4	2.3	2.2	2.0	2.4	2.75	4.5
	3.3	6.55	4.25	3.7	3.6	2.8	2.3	2.1	2.2	2.4	5.45	4.1
	[d]5.75	6.05	4.15	3.65	4.1	3.0	2.3	2.1	2.2	2.4	4.5	3.8
	5.0	10.5	4.2	3.55	4.0	2.7	2.3	2.0	2.65	.....	3.85	3.7
	4.35	.....	5.5	3.6	3.8	2.6	2.3	1.9	2.4	.....	3.6	3.55
	4.1	.....	5.3	3.7	3.6	2.75	3.2	1.9	2.45	2.8	3.5	4.0
	4.05	.....	5.25	.....	3.35	.....	3.3	1.9	.....	2.7	.....	3.7

[a] Slight ice conditions during December, 1901.
[b] Ice passed down the river December 25, 1901.
[c] Ice conditions January and February, 1902.
[d] Ice passed down the river January 27 and February 25, 1902.

Daily gage height, in feet, of North Branch of Potomac River at Piedmont, Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1903.[a]										
1	[b]3.45	5.2	6.7	4.85	3.6	3.75	4.45	2.9	2.8	2.05
2	3.6	6.05	5.55	4.75	3.5	3.55	4.05	2.95	2.65	2.1
3	6.8	6.4	5.0	4.45	3.55	3.4	3.75	2.9	2.5	2.1
4	6.15	8.2	4.65	4.95	4.55	3.3	3.7	3.0	2.4	2.2
5	5.25	6.15	4.5	4.45	3.75	3.2	4.15	3.0	2.3	2.2
6	4.8	5.25	4.5	4.2	3.6	3.25	5.2	2.8	2.5	2.45
7	4.5	4.75	4.6	4.2	3.6	5.25	4.05	2.8	2.5	.....
8	4.2	4.6	5.2	5.15	3.5	4.55	3.65	2.7	2.35	.....
9	3.8	4.35	6.1	5.95	3.45	4.1	3.45	2.65	2.3	.....
10	3.8	4.0	5.4	5.2	3.4	3.9	3.3	2.5	2.7	.....
11	3.8	4.15	4.95	4.7	3.35	4.5	3.25	2.5	2.45	.....
12	4.35	5.05	4.8	4.6	3.2	4.35	3.3	2.5	2.4	.....
13	3.95	4.65	4.5	4.45	3.2	4.8	4.0	2.45	2.3	.....
14	3.75	4.5	4.3	5.3	3.1	4.8	4.1	2.4	2.2	.....
15	3.7	4.8	4.15	5.6	3.1	5.1	3.75	2.4	2.15	.....
16	3.7	6.95	4.0	6.05	3.1	4.55	3.5	2.4	2.1	2.5
17	3.7	5.7	3.9	5.45	3.1	4.3	3.3	2.4	2.35	2.5
18	3.5	4.95	3.8	5.0	3.0	4.0	3.45	2.6	2.7	2.6
19	3.75	4.5	3.7	4.7	3.0	3.6	3.4	2.5	2.65	2.7
20	3.5	4.35	3.6	4.4	2.9	3.65	3.4	2.95	2.5	2.65
21	3.45	4.15	3.75	4.2	2.9	4.5	3.5	2.8	2.3	2.6
22	3.5	4.0	4.55	4.0	2.8	4.15	3.35	2.6	2.2	2.5
23	3.45	3.85	6.65	3.9	3.25	6.1	3.15	2.5	2.2	2.4
24	3.2	3.9	6.0	3.8	3.9	5.15	3.0	2.4	2.15	2.4
25	3.2	3.8	5.15	3.8	4.7	4.45	2.95	2.3	2.1	2.4
26	3.25	3.7	4.7	4.3	4.6	4.0	2.9	2.4	2.1	2.3
27	3.25	4.05	4.4	4.2	4.15	3.85	2.8	2.4	2.05	2.3
28	[c]4.75	8.8	4.25	3.85	4.0	4.1	2.7	2.65	2.1	2.3
29	5.85	.....	4.05	3.7	3.8	6.65	2.65	2.55	2.0	2.3
30	7.3	.....	4.0	3.7	3.7	5.2	2.7	2.7	2.0	2.3
31	5.7	.....	4.1	.....	3.8	.....	3.0	2.8	.....	2.3
1904.[d]										
1	2.9	3.2	4.7	4.7	4.45	3.95	3.0	2.35	1.9	2.0
2	2.95	3.05	4.55	5.25	4.2	3.85	3.1	2.55	1.9	2.0
3	3.0	3.1	4.85	4.75	3.95	3.8	3.05	2.4	2.0	2.05
4	3.55	3.05	5.55	4.35	3.85	3.7	2.85	2.4	1.85	2.0
5	3.1	3.05	4.4	4.15	3.75	3.8	2.7	2.4	2.0	1.95
6	2.95	3.1	4.2	4.0	3.65	3.9	2.65	2.35	2.1	1.95
7	3.15	6.2	4.65	3.9	3.6	3.75	2.7	2.25	1.9	2.0
8	3.0	6.1	5.55	3.9	3.5	3.6	2.8	2.2	1.9	2.15
9	2.9	4.7	4.7	4.3	3.5	3.5	2.8	2.05	1.95	2.1
10	2.8	4.05	4.3	4.15	3.6	3.6	3.45	2.15	2.1	2.1
11	2.8	3.8	4.25	3.95	3.45	3.5	3.2	2.2	2.0	2.15
12	2.8	3.6	4.3	3.85	3.35	3.4	3.05	2.2	2.0	2.2
13	2.7	3.25	4.05	3.85	3.2	3.25	2.9	2.2	2.0	2.4
14	2.7	3.35	3.95	3.7	3.2	3.2	2.8	2.2	2.0	2.25
15	2.6	3.45	3.85	3.7	3.4	3.2	2.7	2.15	2.05	2.2
16	2.6	3.25	3.65	3.75	3.4	3.0	2.6	2.15	2.1	2.15
17	2.6	3.05	3.55	3.9	3.2	3.1	2.5	2.2	2.1	2.1
18	3.15	3.0	3.85	3.8	3.7	3.0	2.45	2.1	2.1	2.05
19	3.0	3.1	3.95	3.7	5.95	2.9	2.35	2.1	2.1	2.1
20	2.95	3.0	4.4	3.6	5.0	3.0	2.35	2.15	2.0	2.1
21	3.8	3.2	4.5	3.5	5.0	3.05	2.5	2.2	2.1	2.2
22	[e]6.8	4.45	4.95	3.45	4.6	3.6	2.9	2.2	2.15	2.2
23	6.65	4.25	6.6	3.4	4.25	3.45	3.2	2.2	2.1	2.2
24	5.3	4.85	5.6	3.35	4.05	3.05	2.9	2.2	2.1	2.2
25	4.25	4.1	5.05	3.45	3.9	2.9	2.7	2.2	1.9	2.2
26	4.0	3.7	4.95	3.9	3.75	2.8	2.7	2.1	2.05	2.2
27	3.55	3.55	4.8	4.65	3.85	2.7	2.6	2.1	2.0	2.1
28	3.25	3.5	4.4	5.25	3.85	2.75	2.5	1.9	2.0	2.2
29	3.3	4.75	4.1	4.95	3.6	3.25	2.6	2.0	2.0	2.1
30	3.4	.....	4.0	4.55	3.5	3.05	2.5	2.0	2.0	2.0
31	3.25	.....	4.45	.....	3.5	.....	2.4	1.9	.....	2.1

[a] Ice conditions January, 1903.
[b] Ice passed down the river January 28, 1903.
[c] Ice conditions January, 1904.
[d] Ice passed down the river January 22, 1904.

gage height, in feet, of North Branch of Potomac River at Piedmont, W. Va.—Continued.

Day.	Jan.	Feb	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.[a]												
	3.05	2.75	[a]3.35	3.85	3.5	4.75	3.3	3.85	2.8	2.3	3.2	3.9
	3.05	2.7	3.25	3.7	3.3	4.0	3.85	3.45	2.8	2.3	3.1	3.75
	3.05	2.65	3.15	3.6	3.3	3.65	3.55	3.2	2.8	2.4	3.05	5.75
	2.95	2.55	3.15	3.55	3.2	3.4	3.4	3.1	2.8	2.45	3.0	4.9
	2.95	2.55	3.35	3.55	3.2	3.3	4.05	3.5	2.7	2.4	3.0	4.4
	2.95	2.55	4.15	3.8	3.2	3.2	4.2	3.15	2.6	2.35	3.15	3.95
	2.9	2.55	[b]4.5	3.95	3.3	3.55	4.3	3.0	2.5	2.3	3.36	3.85
	2.8	2.55	5.0	3.95	3.2	4.15	5.45	2.85	2.5	2.2	3.2	3.7
	2.75	2.55	7.05	3.95	3.1	3.65	4.55	2.8	2.5	2.2	3.2	3.65
	2.65	3.15	7.45	4.0	3.1	3.45	4.05	2.8	2.45	2.2	3.05	3.6
	2.75	3.1	6.3	3.95	3.15	3.85	4.1	3.2	4.2	2.65	3.0	3.3
	2.8	3.05	5.7	3.95	3.5	4.2	4.0	3.25	4.15	3.6	2.9	3.25
	5.95	3.05	5.65	3.85	3.9	4.15	3.95	3.0	3.6	3.05	2.9	3.35
	4.45	3.4	5.3	3.75	3.65	3.75	3.5	2.8	3.25	2.75	2.9	3.25
	3.65	3.3	5.0	3.65	5.02	3.45	3.35	2.85	3.05	2.6	2.9	3.0
	3.3	3.05	4.85	3.55	4.4	3.25	3.3	4.15	2.9	2.55	2.85	2.95
	3.25	2.95	6.	3.5	4.55	3.05	3.15	3.5	2.8	2.5	3.05	3.3
	3.25	2.95	6.45	3.5	4.05	3.65	3.05	3.15	2.8	2.45	3.0	3.2
	3.25	2.85	6.75	3.45	3.95	3.45	2.95	3.0	2.8	3.8	2.9	3.1
	3.25	2.85	6.7	3.75	3.75	3.65	3.35	2.95	2.7	4.45	2.9	3.1
	3.25	2.85	8.	3.85	3.55	3.65	3.3	2.9	2.6	4.0	2.9	4.0
	3.3	2.95	6.75	3.9	3.5	3.65	3.1	2.75	2.55	3.4	2.75	5.4
	3.15	3.4	5.8	3.85	3.4	3.4	3.65	2.65	2.5	3.15	2.75	4.9
	3.05	3.3	5.25	3.7	3.2	3.45	3.6	2.5	2.4	3.0	2.85	4.9
	2.85	3.25	5.65	3.6	3.1	3.65	3.25	4.35	2.45	2.95	2.8	4.05
	2.55	3.25	5.05	3.5	3.1	3.45	3.05	4.9	2.4	4.85	2.8	4.0
	2.55	3.55	4.9	2.8	3.1	4.4	2.9	3.7	2.4	4.4	2.8	3.85
	2.75	3.45	4.6	2.9	3.0	3.65	2.8	3.35	2.3	3.9	2.8	3.65
	2.75	.....	4.3	3.65	2.9	3.35	2.9	3.15	2.3	3.6	3.65	3.8
	2.85	.....	4.15	3.5	2.9	3.2	5.05	3.0	2.3	3.45	4.55	4.15
	2.75	.....	4.0	.....	3.15	.....	4.2	3.0	.....	3.3	.....	3.65
1906.[c]												
	3.55	3.65	2.75	6.05	4.0	3.25	3.0	.....	.....	.....	.....	.....
	3.35	3.55	3.1	5.55	3.9	3.45	2.9	.....	.....	.....	.....	.....
	3.65	3.2	3.3	5.7	4.0	3.3	2.8	.....	.....	.....	.....	.....
	5.65	3.4	5.15	6.0	3.8	3.1	2.8	.....	.....	.....	.....	.....
	5.3	3.5	4.35	6.15	3.7	3.3	3.1	.....	.....	.....	.....	.....
	4.6	3.0	3.95	6.8	3.6	4.6	2.85	.....	.....	.....	.....	.....
	3.9	3.1	3.8	5.	3.7	5.25	2.75	.....	.....	.....	.....	.....
	4.05	3.1	3.8	5.05	3.6	4.7	2.6	.....	.....	.....	.....	.....
	3.65	3.1	3.7	5.15	3.5	4.1	2.6	.....	.....	.....	.....	.....
	3.55	2.9	3.6	6.45	3.5	3.65	2.6	.....	.....	.....	.....	.....
	3.55	2.75	3.4	5.5	3.4	3.35	2.5	.....	.....	.....	.....	.....
	3.7	2.85	3.6	5.45	3.4	3.1	2.65	.....	.....	.....	.....	.....
	3.95	3.0	3.5	4.55	3.3	3.25	2.6	.....	.....	.....	.....	.....
	3.8	3.05	3.5	4.45	3.2	3.1	2.6	.....	.....	.....	.....	.....
	3.8	3.0	3.5	6.15	3.2	3.0	2.55	.....	.....	.....	.....	.....
	3.95	2.75	3.5	5.45	3.1	3.0	.....	.....	.....	.....	.....	.....
	4.15	2.8	3.4	4.85	3.1	2.9	.....	.....	.....	.....	.....	.....
	4.1	2.9	3.15	4.45	3.0	2.9	.....	.....	.....	.....	.....	.....
	4.7	2.8	3.4	4.25	3.0	2.9	.....	.....	.....	.....	.....	.....
	4.35	2.95	4.05	4.1	2.9	2.95	.....	.....	.....	.....	.....	.....
	4.5	3.0	3.8	3.95	2.9	3.1	.....	.....	.....	.....	.....	.....
	4.85	3.2	3.7	4.0	2.8	3.3	.....	.....	.....	.....	.....	.....
	8.2	3.1	3.7	4.0	2.8	3.2	.....	.....	.....	.....	.....	.....
	6.4	3.05	3.75	4.0	2.7	3.1	.....	.....	.....	.....	.....	.....
	5.1	3.1	3.55	4.1	2.7	3.0	.....	.....	.....	.....	.....	.....
	4.6	3.1	3.6	6.5	2.7	3.0	.....	.....	.....	.....	.....	.....
	4.35	3.05	5.05	5.4	2.7	3.6	.....	.....	.....	.....	.....	.....
	4.3	2.6	7.3	4.65	3.35	3.35	.....	.....	.....	.....	.....	.....
	4.15	.....	6.25	4.35	3.45	3.25	.....	.....	.....	.....	.....	.....
	3.95	.....	7.4	4.15	3.2	3.0	.....	.....	.....	.....	.....	.....
	3.8	.....	7.4	.....	3.0	.....	.....	.....	.....	.....	.....	.....

[a] Ice conditions during January, February, and March, 1905.
[b] Ice passed down the river March 7, 1905.
[c] No ice during the winter of 1905–6.

Rating tables for North Branch of Potomac River at Piedmont, W. Va.

JUNE 27, 1899, TO AUGUST 25, 1901.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.80	34	2.60	210	3.30	490	4.00	910
1.90	50	2.70	240	3.40	540	4.10	985
2.00	67	2.80	275	3.50	595	4.20	1,070
2.10	85	2.90	310	3.60	650	4.30	1,160
2.20	105	3.00	350	3.70	710	4.40	1,250
2.30	128	3.10	395	3.80	775	4.50	1,345
2.40	153	3.20	440	3.90	840	4.60	1,445
2.50	180						

AUGUST 26, 1901, TO DECEMBER 31, 1903.[b]

1.90	20	2.60	152	3.30	406	4.00	860
2.00	28	2.70	180	3.40	457	4.10	945
2.10	40	2.80	210	3.50	512	4.20	1,035
2.20	57	2.90	242	3.60	571	4.30	1,130
2.30	77	3.00	277	3.70	635	4.40	1,230
2.40	100	3.10	316	3.80	705	4.50	1,335
2.50	125	3.20	359	3.90	780		

JANUARY 1, 1904, TO DECEMBER 31, 1905.[c]

2.00	15	3.30	347	4.60	1,440	6.80	4,720
2.10	24	3.40	397	4.70	1,550	7.00	5,100
2.20	36	3.50	453	4.80	1,660	7.20	5,500
2.30	51	3.60	515	4.90	1,775	7.40	5,910
2.40	68	3.70	584	5.00	1,890	7.60	6,330
2.50	88	3.80	660	5.20	2,130	7.80	6,760
2.60	110	3.90	742	5.40	2,390	8.00	7,200
2.70	134	4.00	830	5.60	2,670	8.50	8,350
2.80	161	4.10	923	5.80	2,970	9.00	9,550
2.90	191	4.20	1,020	6.00	3,290	9.50	10,800
3.00	224	4.30	1,120	6.20	3,630	10.00	12,100
3.10	261	4.40	1,225	6.40	3,980	10.50	13,450
3.20	302	4.50	1,330	6.60	4,340		

JANUARY 1 TO JULY 15, 1906.[d]

2.50	70	3.60	457	4.70	1,430	6.40	3,785
2.60	88	3.70	519	4.80	1,540	6.60	4,140
2.70	109	3.80	587	4.90	1,655	6.80	4,515
2.80	133	3.90	661	5.00	1,770	7.00	4,900
2.90	160	4.00	740	5.20	2,015	7.20	5,300
3.00	190	4.10	825	5.40	2,270	7.40	5,710
3.10	224	4.20	915	5.60	2,535	7.60	6,130
3.20	262	4.30	1,010	5.80	2,820	7.80	6,570
3.30	304	4.40	1,110	6.00	3,125	8.00	7,030
3.40	350	4.50	1,215	6.20	3,450	8.20	7,500
3.50	401	4.60	1,320				

[a] This table is strictly applicable only for open-channel conditions. It is based on four discharge measurements made during 1899 and 1900. It is fairly well defined between gage heights 1.8 feet and 4.5 feet. As applied to 1901 gage heights it is liable to give estimates several per cent too high, owing to changes in the condition of flow at and below the section during 1901. Above gage height 4.60 feet the table is the same as the 1904–5 table.

[b] This table is strictly applicable only for open-channel conditions. It is based on three discharge measurements made during 1901–1903 and on the form of other curves at this station. It is fairly well defined. Above gage height 4.50 feet the table is the same as the 1904–5 table.

[c] This table is strictly applicable only for open-channel conditions. It is based on discharge measurements made during 1904–1905. It is fairly well defined between gage heights 3.0 feet and 7.5 feet. Below 3 feet the table is based on two measurements at 2 feet. The above table as applied to 1904 gage heights is liable to give estimates several per cent too low above gage height 2.5 feet. As applied to 1905 gage heights it is liable to give estimates several per cent too high below gage height 2.5 feet.

[d] This table is strictly applicable only for open-channel conditions. It is based on three discharge measurements made during 1906 and the form of previous curves at this station. It is well defined between gage heights 3.5 feet and 5.5 feet.

monthly discharge of North Branch of Potomac River at Piedmont, W. Va. [a]

[Drainage area, 410 square miles.]

	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
.....	.....	.....	.....	.....	.....	.....	2.01	.....
.....	.....	.....	.....	.....	.....	.....	3.85	.....
.....	.....	.....	.....	.....	.....	.....	5.08	.....
.....	.....	.....	.....	.....	.....	.....	1.93	.....
.....	.....	.....	.....	.....	.....	.....	6.60	.....
.....	595	292	387	0.944	0.140	.....	[b] 4.81	.....
.....	418	95	209	.510	.588	22	2.64	2.05
.....	350	50	119	.290	.334	16	2.11	1.78
.....	540	67	157	.383	.427	11	3.91	3.48
.....	105	67	88.4	.216	.249	11	2.29	2.04
.....	840	105	275	.671	.749	43	1.76	1.01
.....	2,130	140	421	1.03	1.19	49	2.44	1.25
ar....	.....	.....	.....	.....	.....	.....	39.43	.....
.....	2,970	240	838	2.04	2.35	137	1.72	−0.63
.....	3,130	350	1,032	2.52	2.62	73	3.59	.97
.....	3,210	622	1,306	3.19	3.68	109	3.37	− .31
.....	1,660	465	821	2.00	2.23	170	1.31	− .92
.....	875	240	392	.956	1.10	50	2.22	1.12
.....	6,225	240	804	1.96	2.19	49	4.47	2.28
.....	1,250	116	308	.751	.866	20	4.24	3.37
.....	330	67	136	.332	.383	14	2.64	2.26
.....	240	34	53.6	.131	.146	20	.74	.59
.....	440	67	143	.349	.402	19	2.07	1.67
.....	7,090	81	577	1.41	1.57	29	5.46	3.89
.....	2,970	310	692	1.69	1.95	79	2.46	.51
ar....	7,090	34	592	1.44	19.49	57	34.29	14.80
.....	2,895	310	705	1.72	1.98	54	3.68	1.70
.....	650	292	407	.993	1.03	79	1.30	.27
.....	4,910	292	1,387	3.38	3.90	114	3.42	− .48
.....	6,330	680	2,234	5.45	6.08	102	5.93	− .15
.....	6,225	490	1,681	4.10	4.73	67	7.03	2.30
.....	1,832	395	925	2.26	2.52	72	3.52	1.00
.....	2,260	153	490	1.20	1.38	51	2.69	1.31
.....	1,832	128	409	1.00	1.15	24	4.89	3.74
.....	359	57	149	.363	.405	19	2.09	1.69
.....	138	40	63.5	.155	.179	28	.65	.47
.....	277	28	70.3	.171	.191	7	2.69	2.50
.....	7,545	125	1,472	3.59	4.14	72	5.73	1.59
ear...	7,545	28	831	2.03	27.68	63	43.62	15.94
.....	2,895	242	644	1.57	1.81	57	3.19	1.38
.....	13,450	210	1,062	2.64	2.75	72	3.83	1.08
.....	7,430	990	2,578	6.29	7.25	173	4.18	−3.07
.....	5,200	542	1,980	4.83	5.39	130	4.14	−1.25
.....	945	242	483	1.18	1.36	42	3.26	1.90
.....	406	100	219	.534	.596	14	4.34	3.74
.....	1,605	77	265	.646	.745	21	3.62	2.87
.....	226	20	85.8	.209	.241	11	2.14	1.90
.....	166	20	40.9	.100	.112	4	2.84	2.73
.....	635	100	213	.520	.600	20	3.00	2.40
.....	2,460	100	288	.702	.783	34	2.32	1.54
.....	6,330	484	1,764	4.30	4.96	94	5.29	.33
ar....	13,450	20	804	1.96	26.60	63	42.15	15.55

[a] See description and footnotes to the rating tables.
[b] Precipitation for complete month June, 1899.
[c] Discharge interpolated October 28 and 29, 1902.

Estimated monthly discharge of North Branch of Potomac River at Piedmont, W. Va.—Continued.

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1903.								
January	5,700	359	1,292	3.15	3.63	102	3.57	−0.06
February	9,070	635	2,223	5.42	5.64	103	5.50	−.14
March	4,530	571	1,662	4.05	4.67	122	3.82	−.85
April	3,375	635	1,506	3.67	4.10	113	3.64	−.46
May	1,550	210	580	1.41	1.63	51	3.18	1.55
June	4,435	359	1,292	3.15	3.51	54	6.50	2.99
July	2,130	166	570	1.39	1.60	32	4.96	3.36
August	277	77	163	.398	.459	14	3.18	2.72
September	210	28	90.5	.221	.247	14	1.77	1.52
October[a]	180	34	103	.251	.289	12	2.36	2.07
November	603	57	134	.327	.365	20	1.78	1.42
December	1,282	48	193	.471	.543	37	1.47	.93
The year	9,070	28	817	1.99	26.68	64	41.73	15.05
1904.[b]								
January	4,720	110	643	1.58	1.82	59	3.07	1.25
February	3,630	224	795	1.90	2.11	108	1.96	−.15
March	4,340	484	1,433	3.53	4.07	163	2.50	−1.57
April	2,195	372	937	2.31	2.58	98	2.62	.04
May	3,210	302	792	1.95	2.25	70	3.20	.95
June	786	134	392	.966	1.08	27	3.95	2.87
July	425	60	160	.394	.454	12	3.69	3.24
August	99	9	37	.091	.105	6	1.96	1.85
September	30	6	17	.042	.047	3	1.81	1.76
October	68	12	28	.069	.080	5	1.76	1.68
November	51	15	34	.084	.094	17	.54	.45
December	1,600	15	243	.599	.691	24	2.92	2.23
The year	4,720	6	459	1.13	15.38	51	29.98	14.60
1905.[b]								
January	3,210	99	360	.887	1.02	33	3.13	2.11
February	484	99	232	.571	.595	34	1.75	1.16
March	7,420	282	2,484	6.12	7.06	201	3.52	−3.54
April	830	161	585	1.44	1.61	82	1.97	.36
May	1,914	191	496	1.22	1.41	49	2.87	1.46
June	1,605	242	588	1.45	1.62	40	4.03	2.41
July	2,460	161	653	1.61	1.86	28	6.55	4.69
August	1,775	88	376	.926	1.07	28	3.88	2.81
September	1,020	51	195	.480	.536	25	2.16	1.62
October	1,718	36	348	.857	.988	24	4.08	3.09
November	1,385	148	267	.658	.734	31	2.36	1.63
December	2,895	208	815	2.01	2.32	74	3.13	.81
The year	7,420	36	617	1.52	20.82	53	39.43	18.61
1906.								
January	7,500	327	1,255	3.06	3.53			
February	488	88	220	.537	.559			
March	5,710	121	1,161	2.83	3.26			
April	4,515	700	2,013	4.91	5.48			
May	740	109	323	.788	.908			
June	2,078	160	413	1.01	1.13			
July 1–15	224	70	120	.293	.163			

[a] Discharge interpolated October 7–15, 1903.
[b] Drainage area of 406 square miles used to obtain 1904 and 1905 run-off.

GEORGES CREEK AT WESTERNPORT, MD.

Georges Creek rises on Mount Savage, in the northwestern part of Allegany County, Md., and flows southwestward into North Branch of Potomac River at Westernport. Its length is about 15 miles.

The gaging station was established May 4, 1905, and was discontinued July 16, 1906. It is located at a highway bridge in Westernport, Md., about one-half mile above the mouth of the creek.

Above the station the channel is straight for about 50 feet and then makes a sharp bend. Below the station it is straight for 300 feet. The current is swift. Both banks are fairly high, clean, and do not overflow. The bed of the stream is rocky and shifting. There is but one channel at all stages.

Discharge measurements were made from the upstream side of the bridge to which the gage is attached. The initial point for soundings is the inside face of the left abutment, upstream side.

A standard chain gage is attached to the middle of the upstream side of the bridge. The length of the chain from the end of the weight to the marker is 16.23 feet. The gage was read twice each day by G. A. Biggs. Bench mark No. 1 is the top of the downstream bedplate at the left abutment, on the downstream corner toward the railroad track. Its elevation is 11.58 feet above the datum of the gage. Bench mark No. 3 is the top of the pulley wheel of the gage. Its elevation was 15.88 feet above the datum of the gage May 4, 1905.

The bed of Georges Creek at the gaging section is rather unstable and subject to frequent changes on account of the high velocity of the current. The estimates are therefore subject to varying errors of from 5 to 20 per cent of the true flow. Ice conditions did not affect the estimates during the winter of 1905–6.

Discharge measurements of Georges Creek at Westernport, Md.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
April 18	1.60	53	March 16	1.49	65
May 4	1.35	33	March 30	3.38	1,230
June 7	1.98	131	April 10	2.50	476
July 17	1.58	43	May 28	2.25	353
November 7	1.35	45			

Daily gage height, in feet, of Georges Creek at Westernport, Md.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1						1.45	1.38	1.22	1.05	0.95	1.5	1.62
2						1.45	1.58	1.12	1.05	1.28	1.5	1.8
3						1.38	1.32	1.1	1.08	1.18	1.45	2.35
4					1.45	1.3	1.48	1.1	1.12	1.1	1.38	2.22
5					1.4	1.25	1.52	1.08	1.1	1.05	1.4	2.12
6					1.42	1.2	1.48	1.05	1.1	1.02	1.52	2.35
7					1.5	1.98	3.45	1.05	1.05	1.0	1.4	2.35
8					1.4	1.58	3.38	1.05	1.0	1.0	1.32	2.22
9					1.35	1.42	2.65	1.05	1.0	1.0	1.25	2.12
10					1.38	1.35	2.15	1.05	1.28	.98	1.2	2.02
11					1.38	2.05	2.05	1.08	2.55	1.75	1.12	1.9
12					1.5	1.98	1.98	1.12	1.9	1.55	1.1	1.88
13					1.38	1.85	1.92	1.15	1.65	1.25	1.05	1.82
14					1.48	1.72	1.8	1.12	1.5	1.12	1.0	1.78
15					1.72	1.62	1.7	1.28	1.42	1.08	.95	1.62
16					1.68	1.52	1.62	1.25	1.32	1.05	.98	1.45
17					1.65	1.5	1.52	1.12	1.38	1.0	1.0	1.3
18					1.62	1.48	1.42	1.05	1.28	1.0	1.0	1.3
19					1.58	1.4	1.32	1.02	1.22	1.18	1.02	1.35
20					1.52	1.55	1.4	1.0	1.18	2.3	1.02	1.4
21					1.5	1.48	1.38	1.0	1.12	1.65	1.0	3.4
22					1.45	1.42	1.35	1.0	1.1	1.52	1.0	3.08
23					1.4	1.38	1.7	.98	1.05	1.48	1.0	2.2
24					1.38	1.5	1.48	.92	1.05	1.42	1.0	2.2
25					1.28	1.55	1.22	1.72	1.0	1.52	1.08	2.12
26					1.28	1.4	1.18	1.65	1.0	2.02	1.05	2.15
27					1.25	1.32	1.15	1.45	1.0	1.85	1.08	1.98
28					1.3	1.25	1.15	1.25	1.0	1.72	1.	1.95
29					1.3	1.22	1.2	1.1	.95	1.62	1.55	2.08
30					1.28	1.2	1.45	1.12	.95	1.52	1.65	1.88
31					1.32		1.38	1.08		1.5		1.75
1906.												
1	1.68	1.8	1.6	3.18	1.68	1.65	1.18					
2	1.55	1.8	1.78	2.98	1.72	1.55	1.15					
3	2.3	1.75	2.05	2.88	1.62	1.55	1.15					
4	2.58	1.72	2.1	2.92	1.52	1.32	1.1					
5	2.45	1.68	2.02	2.85	1.5	1.6	1.1					
6	2.38	1.65	1.98	2.52	1.55	1.68	1.1					
7	2.2	1.6	1.8	2.32	1.5	2.22	1.05					
8	2.2	1.55	1.75	2.32	1.5	2.25	1.05					
9	1.88	1.52	1.68	2.55	1.45	1.95	1.05					
10	1.95	1.5	1.6	2.58	1.4	1.8	1.1					
11	1.95	1.45	1.55	2.32	1.4	1.72	1.1					
12	2.0	1.45	1.52	2.32	1.4	1.75	1.1					
13	1.95	1.42	1.5	2.22	1.4	1.75	1.1					
14	1.88	1.4	1.5	2.22	1.42	1.7	1.05					
15	1.78	1.4	1.5	2.2	.4	1.62	1.02					
16	1.82	1.4	1.45	2.22	1.3	1.55						
17	2.0	1.4	1.32	2.12	1.32	1.25						
18	2.05	1.4	1.32	2.12	1.32	1.2						
19	2.12	1.4	1.38	2.22	1.25	1.2						
20	2.15	1.45	1.5	2.0	1.22	1.35						
21	2.18	1.45	1.55	2.05	1.2	1.35						
22	2.22	1.4	1.58	1.9	1.2	1.35						
23	3.28	1.35	1.55	1.88	1.15	1.38						
24	3.08	1.32	1.58	1.88	1.15	1.4						
25	2.68	1.3	1.6	1.82	1.1	1.3						
26	2.2	1.3	1.68	1.9	1.1	1.32						
27	2.12	1.38	2.62	1.85	2.02	1.38						
28	2.1	1.42	3.2	1.75	2.08	1.25						
29	2.05		3.2	1.7	2.2	1.2						
30	1.98		3.42	1.72	1.95	1.2						
31	1.9		3.45		1.88							

Rating tables for Georges Creek at Westernport, Md.

MAY 4, 1905, TO JUNE 6, 1905.[a]

Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*
1.20	22	1.60	66
1.30	29	1.70	87
1.40	38	1.80	112
1.50	50		

JUNE 7 TO SEPTEMBER 10, 1905.[b]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.90	5	1.60	48	2.30	252	3.00	700
1.00	8	1.70	64	2.40	301	3.10	780
1.10	11	1.80	84	2.50	355	3.20	865
1.20	15	1.90	108	2.60	415	3.30	955
1.30	20	2.00	137	2.70	480	3.40	1,045
1.40	27	2.10	170	2.80	550	3.50	1,140
1.50	36	2.20	208	2.90	625		

SEPTEMBER 11, 1905, TO JULY 15, 1906.[c]

0.90	10	1.70	115	2.50	495	3.30	1,150
1.00	15	1.80	145	2.60	560	3.40	1,250
1.10	21	1.90	180	2.70	630	3.50	1,350
1.20	29	2.00	220	2.80	705	3.60	1,455
1.30	39	2.10	265	2.90	785	3.70	1,560
1.40	52	2.20	315	3.00	870	3.80	1,670
1.50	69	2.30	370	3.10	960	3.90	1,780
1.60	90	2.40	430	3.20	1,055	4.00	1,895

is table is based on one discharge measurement made during 1905 and the form of the 1906 curve. ot well defined.
is table is based on three discharge measurements made during 1905 and the form of the 1906 curve. irly well defined between gage heights 1.5 feet and 2.0 feet.
is table is strictly applicable only for open-channel conditions. It is based on five discharge measnts made during 1905 and 1906. It is fairly well defined between gage heights 1.3 feet and 3.5 feet.

Estimated monthly discharge of Georges Creek at Westernport, Md.

[Drainage area, 76 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
-31	92	26	44.8	0.589	0.613
	154	15	45.7	.601	.670
	1,092	13	127	1.67	1.92
t	68	6	15.1	.199	.229
nber	528	8	46.4	.611	.682
er	370	12	65.8	.866	.998
ber	102	12	33.8	.445	.496
ber	1,250	39	267	3.51	4.05
1906.					
ry	1,131	80	320	4.21	4.85
ary	145	39	71.2	.937	.976
	1,300	42	260	3.42	3.94
	1,036	115	378	4.97	5.54
	315	21	83.0	1.09	1.26
	342	29	91.4	1.20	1.34
-15	27	16	20.8	.274	.153

WILLS CREEK AT CUMBERLAND, MD.

Wills Creek rises on the western slope of Savage Mountain, southeastern part of Somerset County, Pa., and flows northwe to Mance, eastward to Hyndman, Pa., and southward to Cumb Md., where it enters North Branch of Potomac River. Its le about 25 miles.

The gaging station was established May 5, 1905, and was tinued July 15, 1906. It is located at the highway bridge at th end of "The Narrows," Cumberland, Md.

The channel is straight for 200 feet above and 500 feet bel station. The current is fairly swift. Both banks are high and overflow. The bed of the stream is rocky, very rough, and pern There are two channels at all but very low stages.

Discharge measurements were made from the downstream the two-span bridge to which the gage is fastened. The initia for soundings is the face of the right abutment.

A standard chain gage is fastened to the downstream side bridge, near the middle of the right span. The length of th from the end of the weight to the marker is 26.98 feet. The ga read twice each day by H. E. McKenzie. Bench mark No. square chisel draft on the top of the bridge-seat stone at the stream side of the right abutment. Its elevation is 21.88 feet the datum of the gage. Bench mark No. 2 is the top of the wheel of the gage. Its elevation was 26.65 feet above the da the gage March 17, 1906.

Estimates are considered to be within 5 per cent of the tru Ice conditions probably did not affect the flow during the wi 1905–6.

Discharge measurements of Wills Creek at Cumberland, Md.

Date.	Gage height.	Discharge.	Date.	Gage height.	D
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*S*
April 17	4.20	236	March 17	4.01	
May 6	3.72	130	April 2	6.32	
June 8	4.22	248	April 10	6.05	
November 6	3.68	130	April 11	5.88	
			May 26	3.27	

Daily gage height, in feet, of Wills Creek at Cumberland, Md.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1						3.72	3.65	3.55	3.62	3.05	3.92	4.52
2						3.95	4.0	3.45	3.55	3.2	3.8	4.38
3						3.82	3.75	3.4	3.6	3.35	3.75	7.06
4						3.7	3.65	3.3	3.55	3.3	3.75	6.22
5						3.68	3.6	3.3	3.45	3.18	3.65	5.45
6					3.7	3.6	3.58	3.28	3.38	3.08	3.65	5.02
7					4.0	4.2	6.58	3.2	3.32	3.0	3.65	4.7
8					3.82	4.25	6.7	3.18	3.22	3.0	3.6	4.5
9					3.8	4.05	5.7	3.15	3.2	3.0	3.6	4.38
10					3.8	3.9	5.42	3.08	3.18	3.0	3.55	4.25
11					3.8	6.2	5.05	3.1	5.25	4.05	3.5	4.05
12					4.08	5.42	4.7	3.8	5.0	4.0	3.45	4.02
13					3.98	4.88	4.6	3.48	4.6	3.72	3.42	3.98
14					4.05	4.48	4.98	3.45	4.15	3.55	3.4	3.8
15					5.42	4.25	4.58	5.85	3.98	3.42	3.35	3.55
16					5.08	4.52	4.32	4.85	3.82	3.4	3.38	3.42
17					4.85	3.9	4.1	4.35	3.72	3.32	3.45	3.32
18					4.6	3.9	3.85	4.02	3.78	3.3	3.4	3.68
19					4.45	3.9	3.82	3.85	3.68	3.3	3.35	3.92
20					4.28	3.7	4.25	3.72	3.55	5.15	3.3	3.75
21					4.1	4.05	3.88	3.68	3.45	4.65	3.25	6.6
22					4.0	4.15	3.88	3.52	3.4	4.38	3.2	6.25
23					3.92	4.32	4.32	3.42	3.32	4.15	3.25	5.8
24					3.82	4.45	3.98	3.32	3.28	4.02	3.3	5.32
25					3.72	4.5	3.8	5.1	3.18	3.9	3.35	5.0
26					3.62	4.38	3.68	4.58	3.15	4.45	3.3	4.75
27					3.98	4.3	3.6	4.18	3.1	4.25	3.25	4.55
28					3.7	4.02	3.55	3.98	3.1	4.18	3.25	4.35
29					3.6	3.9	3.6	3.82	3.05	4.12	5.1	5.22
30					3.52	3.72	3.85	4.08	3.05	4.02	4.88	5.05
31					3.52	.....	3.65	3.72	.....	4.0	.....	4.65
1906.												
1	4.45	4.25	3.5	6.7	4.02	3.5	3.35	.....	.....	.....	.....	.....
2	4.25	4.05	3.5	6.3	4.25	3.48	3.3	.....	.....	.....	.....	.....
3	4.45	3.7	4.15	6.3	4.18	3.38	3.25	.....	.....	.....	.....	.....
4	5.95	4.02	5.25	6.2	4.08	3.3	3.25	.....	.....	.....	.....	.....
5	5.78	4.02	4.6	6.32	4.0	3.5	3.2	.....	.....	.....	.....	.....
6	5.5	3.7	4.25	6.32	4.0	3.65	3.18	.....	.....	.....	.....	.....
7	5.12	3.6	4.25	5.45	3.9	6.6	3.15	.....	.....	.....	.....	.....
8	4.95	3.68	4.3	5.3	3.88	5.5	3.1	.....	.....	.....	.....	.....
9	4.65	3.75	4.22	5.6	3.8	4.75	3.05	.....	.....	.....	.....	.....
10	4.38	3.75	4.18	6.0	3.8	4.3	3.05	.....	.....	.....	.....	.....
11	4.32	3.7	4.12	5.9	3.8	4.0	3.05	.....	.....	.....	.....	.....
12	4.45	3.7	4.08	5.6	3.75	3.8	3.18	.....	.....	.....	.....	.....
13	4.42	3.6	4.02	5.42	3.7	3.78	3.08	.....	.....	.....	.....	.....
14	4.4	3.68	4.05	5.1	3.65	3.72	3.02	.....	.....	.....	.....	.....
15	4.45	3.65	4.05	6.3	3.6	3.68	.....	.....	.....	.....	.....	.....
16	4.7	3.6	4.1	5.92	3.55	3.6	.....	.....	.....	.....	.....	.....
17	5.0	3.55	4.1	5.58	3.6	3.55	.....	.....	.....	.....	.....	.....
18	4.88	3.5	4.1	5.32	3.52	3.62	.....	.....	.....	.....	.....	.....
19	5.1	3.5	4.1	5.02	3.48	3.85	.....	.....	.....	.....	.....	.....
20	5.02	3.5	4.18	4.88	3.45	3.9	.....	.....	.....	.....	.....	.....
21	5.12	3.7	4.2	4.72	3.45	3.88	.....	.....	.....	.....	.....	.....
22	5.25	3.68	4.2	4.68	3.4	3.78	.....	.....	.....	.....	.....	.....
23	7.3	3.58	4.2	4.62	3.4	3.78	.....	.....	.....	.....	.....	.....
24	6.95	3.55	4.2	4.52	3.35	3.7	.....	.....	.....	.....	.....	.....
25	5.88	3.65	4.2	4.5	3.3	3.58	.....	.....	.....	.....	.....	.....
26	5.48	3.5	4.2	4.45	3.3	3.52	.....	.....	.....	.....	.....	.....
27	5.08	3.5	6.1	4.4	3.5	3.5	.....	.....	.....	.....	.....	.....
28	4.9	3.5	7.7	4.32	3.9	3.55	.....	.....	.....	.....	.....	.....
29	4.75	.....	7.2	4.22	3.65	3.5	.....	.....	.....	.....	.....	.....
30	4.55	.....	7.05	4.12	3.55	3.38	.....	.....	.....	.....	.....	.....
31	4.42	.....	7.9	.....	3.4	.....	.....	.....	.....	.....	.....	.....

Rating table for Wills Creek at Cumberland, Md., from May 6, 1905, to July 14, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.00	30	4.30	270	5.60	860	6.80	2,030
3.10	38	4.40	301	5.70	930	6.90	2,160
3.20	48	4.50	334	5.80	1,005	7.00	2,295
3.30	60	4.60	368	5.90	1,085	7.10	2,435
3.40	73	4.70	404	6.00	1,170	7.20	2,575
3.50	88	4.80	442	6.10	1,260	7.30	2,720
3.60	104	4.90	482	6.20	1,355	7.40	2,870
3.70	122	5.00	525	6.30	1,455	7.50	3,020
3.80	142	5.10	570	6.40	1,560	7.60	3,170
3.90	164	5.20	620	6.50	1,670	7.70	3,320
4.00	188	5.30	675	6.60	1,785	7.80	3,480
4.10	214	5.40	735	6.70	1,905	7.90	3,640
4.20	241	5.5	795				

[a] This table is strictly applicable only for open-channel conditions. It is based on nine discharge measurements made during 1905 and 1906. It is well defined between gage heights 3.0 feet and 6.5 feet.

Estimated monthly discharge of Wills Creek at Cumberland, Md.

[Drainage area, 240 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
May 6–31	747	91	221	0.921	0.891
June	1,355	104	272	1.13	1.26
July	1,905	98	353	1.47	1.70
August	1,015	36	174	.725	.836
September	647	34	128	.533	.595
October	595	30	149	.621	.716
November	570	48	115	.479	.534
December	2,407	63	529	2.20	2.54
1906.					
January	2,720	256	637	2.65	3.06
February	256	88	122	.508	.529
March	3,640	88	626	2.61	3.01
April	1,905	219	806	3.36	3.75
May	256	60	126	.525	.605
June	1,785	60	207	.862	.962
July 1–14	66	32	44.6	.186	.097

NORTH BRANCH OF POTOMAC RIVER AT CUMBERLAND, MD.[a]

Gage-height records were obtained at this station from June 11, 1894, to November 20, 1897. The gage was located about 1,000 feet below the mouth of Wills Creek and consisted of a vertical rod 10 feet long, bolted to the east side of the abutment of the head-gate of the eastern feeder of the Chesapeake and Ohio Canal, just above the diversion dam. The top of the rod, or the 10.00-foot mark, was 5.40 feet below the top of the abutment. The crest of the dam was at elevation about 2.65 feet above the datum of the gage, hence for stages below that point no water passed the gaging section, which was below the dam, all flow being diverted to the canal. Discharge measurements of the river were made from the West Virginia Central Railroad bridge, about 200 yards below the dam. The channel is straight both above

[a] For description of Weather Bureau station maintained at this point see p. 42.

and below the bridge. The left bank does not overflow; the right bank is liable to overflow at times of high water. The bed of the stream is composed of bowlders and loose rocks and is not liable to change. At high water the section is fairly smooth and the velocity high. At low water rocks, riffles, and angular currents appear, making it difficult to obtain accurate discharge measurements. Measurements of the canal feeders were also made near the head-gates.

All estimates previously published for this station have been revised. The monthly discharge as given in the accompanying table is for the section at the bridge only, the flow diverted to the canal feeders not being included, as it is an uncertain function of the total discharge of the river. (See discharge measurements.) No statement of the run-off is given, because the flow in the canal is a large percentage of the total run-off of the drainage basin above Cumberland.

Owing to the poor conditions at this station the measurements plot somewhat erratically, but since the rating curve is defined by a large number of measurements the monthly estimates which are based on it are probably within 10 per cent of the true results for normal conditions of flow above gage height 3.0 feet. Estimates for stages below 3.0 feet are somewhat uncertain. Ice conditions at this station were not recorded by the observer. It is probable, however, that ice collecting at the crest of the dam may at times have affected the gage heights, and hence the estimates.

Discharge measurements of North Branch of Potomac River at Cumberland, Md.

Date.	Gage height.	Discharge of river.	Discharge of canal feeders.	Date.	Gage height.	Discharge of river.	Discharge of canal feeders.
1894.	*Feet.*	*Second-feet.*	*Second-feet.*	1896.	*Feet.*	*Second-feet.*	*Second-feet.*
May 24	.....	3,037	.....	June 24	3.31	696	126
				August 6	3.30	552	54
1895.				November 18	3.38	548	217
March 30	4.50	3,446	.....				
April 10	5.40	6,054	.....	1897.			
April 25	3.30	630	.....	February 10	3.75	1,307	.....
May 3	3.75	1,728	.....	March 27	3.93	1,971	24
May 9	3.40	777	.....	June 25	3.00	289	136
May 23	3.40	831	45	September 1	2.60	0	86
June 5	2.95	216	40	September 22	2.70	7	85
June 6	3.10	530	79				
June 13	3.00	149	38	1898.			
July 17	3.05	266	79	May 12	3.80	1,659	170

Daily gage height, in feet, of North Branch of Potomac River at Cumberland, Md.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	D
1894.												
1							2.9	3.0	0.7	1.7	3.5	
2							2.9	3.0	.5	3.0	3.5	
3							2.9	3.1	.6	2.8	3.3	
4							2.8	3.1	.6	2.7	3.0	
5							2.8	2.9	.5	2.5	2.9	
6							2.8	2.8	1.0	2.3	3.0	
7							2.8	2.8	1.0	1.7	3.0	
8							2.8	2.6	1.1	1.5	3.0	
9							2.8	2.5	1.1	1.6	3.1	
10							2.8	2.1	1.1	1.9	3.1	
11						3.5	2.7	2.0	1.0	2.0	3.2	
12						3.4	2.6	2.1	1.0	3.0	3.1	
13						3.4	2.6	2.0	1.2	2.9	3.1	
14						3.3	2.7	3.0	1.2	2.9	3.1	
15						3.3	2.6	3.0	1.3	2.9	3.0	
16						3.3	2.5	2.9	1.4	2.9	3.0	
17						3	2	2.8	1.7	2.9	3.0	
18						3.3	2.3	2.7	2.9	2.9	3.0	
19						3.3	2.2	2.0	2.9	2.8	2.3	
20						3.2	2.0	1.9	3.1	2.8	2.3	
21						3.1	1.9	1.9	3.2	2.7	3.1	
22						3.1	1.5	2.5	3.2	2.7	3.0	
23						3.4	2.0	3.0	2.9	2.7	3.0	
24						3.4	3.0	2.8	2.9	2.2	3.0	
25						3.3	3.0	2.8	2.8	1.9	3.2	
26						3.3	2.9	2.5	2.7	1.8	3.1	
27						3.3	2.9	1.9	2.7	1.7	3.0	
28						3.3	2	1.8	2.5	1.7	3.0	
29						3.2	2	1.3	2.0	1.7	3.0	
30						3.0	2	1.0	1.8	1.7	3.0	
31							2.9	.9		2.0		
1895.												
1	3.0	3.6	6.0	3.9	3.4	3.0	3	2.8	1.0			
2	3.0	3.6	5.7	3.8	3.8	3.0	3	2.7	1.0			
3	3.0	3.5	4.9	4.4	3.8	3.0	3	2.7	1.0			
4	3.0	3.5	4.6	3.9	3.6	2.9	3	2.7	.9			
5	3.0	3.5	4.2	3.8	3.6	2.9	3.1	2.7	.9			
6	3.1	3.5	4.0	3.7	3.4	3.0	3.2	2.6	.9			
7	4.8	3.5	3.8	3.6	3.3	3.0	3.2	2.6	.8			
8	6.0	3.5	3.8	3.8	3.2	3.0	3.2	2.6	.8			
9	4.8	3.5	4.2	5.6	3.4	2.9	3.3	2.5	.7			
10	4.7	3.5	4.0	5.5	3.2	2.9	3.7	2.5	.5			
11	4.1	3.5	4.0	4.7	3.2	2.9	3.4	2.4	.5			
12	3.8	3.4	3.8	4.7	3.7	2.8	3.2	2.4	.6			
13	3.5	3.4	3.8	3.9	3.7	2.8	3.2	2.4	1.1			
14	3.5	3.4	4.5	3.8	3.7	3.3	3.3	2.3	1.2			
15	3.5	3.4	4.8	3.8	3.5	3.3	3.3	2.2	1.0			
16	3.9	3.3	5.2	3.8	3.3	3.2	3.3	2.1	.9			
17	3.9	3.4	4.7	3.8	3.4	3.2	3.0	2.0	.9			
18	3.9	3.4	4.5	3.7	3.4	3.1	3.0	1.9	.8			
19	3.8	3.4	4.3	3.6	3.4	3.0	2.9	1.8	.7			
20	3.8	3.4	4.1	3.5	3.3	3.0	2.9	1.7	.5			
21	3.9	3.4	3.8	3.4	3.4	2.9	2.7	1.6	.4			
22	4.6	3.4	3.7	3.4	3.4	3.0	2.7	1.3	.3			
23	4.0	3.4	3.7	3.3	3.4	3.0	2.7	1.2	.2			
24	3.7	3.4	3.7	3.3	3.4	3.0	2.7	1.1	.1			
25	3.6	3.4	3.7	3.2	3.3	2.9	2.7	1.0	(a)			
26	3.5	3.6	4.5	3.3	3.2	3.0	2.7	.9				
27	3.5	4.1	4.3	3.3	3.3	3.0	2.7	.9				
28	3.4	5.0	4.3	3.3	3.2	3.3	2.8	.9				
29	3.4		5.1	3.3	3.1	3.2	2.9	.9				
30	3.7		4.5	3.4	3.1	3.0	2.9	.8				
31	3.7		4.5		3.1		2.8	.9				

a Water surface below gage zero September 25 to December 21, 1895.

age height, in feet, of North Branch of Potomac River at Cumberland, Md.—Cont'd.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1896.												
	2.9	4.6	3.9	5.0	4.5	3.6	3.1	3.8	2.6	5.5	3.1	3.7
	2.9	4.8	3.7	4.8	4.5	3.5	3.1	3.8	2.7	4.5	3.1	3.5
	3.0	4.0	3.0	4.4	4.5	3.4	3.1	3.8	2.7	4.5	3.1	3.4
	2.9	3.8	3.3	4.2	4.5	3.5	3.1	3.7	2.7	3.5	3.2	3.3
	2.9	3.8	3.1	3.8	3.4	3.3	3.1	3.3	2.7	3.4	3.2	3.3
	2.9	3.8	3.1	3.8	3.3	3.3	2.9	3.3	2.8	3.3	5.5	3.3
	2.9	4.5	3.1	3.7	3.1	3.8	2.9	3.2	2.9	3.1	4.5	3.3
	2.9	3.9	3.6	3.7	3.0	3.7	2.9	3.2	2.9	3.1	3.8	3.2
	2.9	3.0	3.4	3.7	3.0	3.4	3.1	3.4	2.9	3.1	3.8	3.3
	2.9	3.4	3.3	3.7	3.0	3.4	3.7	3.4	2.9	3.0	3.7	3.3
	2.9	3.1	3.3	3.7	2.9	3.4	3.4	3.3	2.8	3.0	3.6	3.4
	3.0	3.3	3.4	4.3	2.9	2.4	3.3	3.3	2.7	3.1	3.5	3.6
	3.0	4.9	3.1	4.3	3.5	3.2	3.1	3.1	2.9	3.1	3.5	3.4
	3.0	4.1	3.1	4.1	3.5	3.2	3.0	3.6	3.0	3.0	3.4	3.3
	3.0	3.8	3.1	3.9	3.3	3.3	3.0	3.5	3.1	3.0	3.2	3.3
	3.0	3.8	3.2	3.8	3.2	3.3	3.0	3.3	3.5	3.0	3.1	3.3
	3.0	3.5	3.3	3.8	3.1	3.7	3.0	3.1	3.0	3.0	3.1	3.3
	3.0	3.5	3.3	3.7	3.4	4.1	3.3	3.0	3.0	3.0	3.2	3.3
	2.9	3.2	3.5	3.5	3.5	3.7	3.1	2.9	3.0	2.9	3.3	3.3
	2.9	3.2	3.6	3.5	3.8	3.6	3.1	2.9	2.9	2.9	3.3	3.3
	3.0	3.2	3.7	3.5	3.8	3.3	3.3	3.0	3.0	3.1	3.2	3.2
	3.0	3.2	3.7	3.5	3.6	3.3	4.0	3.0	3.1	3.1	3.3	3.2
	3.0	3.3	4.0	3.3	3.4	3.2	4.7	3.0	3.1	3.1	3.3	3.2
	3.1	3.1	3.9	3.4	3.4	3.5	4.6	3.2	3.0	3.3	3.4	3.2
	3.5	3.3	3.7	3.5	3.5	3.5	10.0	3.0	3.0	3.7	3.3	3.2
	3.3	3.3	4.0	3.5	3.5	3.6	6.5	2.9	3.0	3.5	3.3	3.2
	3.1	3.3	5.0	3.5	4.0	3.5	4.7	2.9	3.0	3.2	3.2	3.1
	3.0	3.2	4.5	3.5	3.7	3.3	4.9	2.9	2.9	3.2	3.2	3.1
	3.0	3.7	5.8	3.5	4.1	3.3	4.5	2.9	2.9	3.1	3.9	3.1
	3.7	.....	8.0	3.4	4.0	3.2	4.5	2.9	10.0	3.1	4.0	3.1
	4.2	.....	6.0	.....	3.8	.....	4.5	2.8	.....	3.1	.....	3.2
1897.												
	3.2	3.4	4.0	3.5	3.5	2.9	2.7	3.0	2.6	2.2	2.8	.....
	3.2	3.5	3.8	3.4	7.5	2.8	2.7	3.0	2.5	2.0	3.0	.....
	3.3	3.6	3.9	3.4	5.5	2.8	2.7	2.9	2.5	1.9	3.0	.....
	3.3	3.4	5.2	3.7	5.0	2.8	2.7	2.9	2.5	1.7	3.1	.....
	4.0	3.4	4.9	3.8	4.6	2.8	2.7	3.5	2.4	1.7	3.0	.....
	4.0	3.5	6.0	3.7	4.1	2.8	2.6	3.2	2.4	1.6	2.9	.....
	3.7	4.5	5.0	3.6	4.1	2.8	2.6	3.1	2.2	1.5	2.9	.....
	3.4	4.2	4.4	5.2	3.9	2.8	2.7	3.2	1.9	1.4	3.0	.....
	3.3	4.0	4.6	5.4	3.7	2.9	2.7	3.1	1.8	1.4	4.0	.....
	3.4	3.7	4.2	4.5	3.7	2.7	2.7	3.0	1.8	1.5	3.4	.....
	3.2	3.6	4.0	4.5	3.6	2.7	2.8	3.0	1.7	1.3	3.4	.....
	3.2	3.5	4.0	4.1	4.0	2.7	2.9	2.9	1.6	1.3	3.3	.....
	3.2	3.7	3.9	4.0	4.4	2.6	2.9	2.9	1.5	1.3	3.2	.....
	3.2	4.0	3.8	3.8	5.4	2.5	2.8	2.8	1.4	1.4	3.2	.....
	3.2	4.2	4.0	3.9	4.6	2.5	2.8	3.0	1.3	1.5	3.5	.....
	3.2	4.7	3.8	3.9	4.3	3.0	2.8	3.0	1.2	1.5	3.5	.....
	3.4	4.5	3.7	3.7	3.9	3.0	2.7	2.9	1.2	1.4	3.4	.....
	3.7	5.0	4.0	3.7	3.8	2.9	2.8	2.8	3.2	1.4	3.3	.....
	3.5	4.8	4.5	3.6	3.7	2.9	2.8	2.9	3.0	1.4	3.3	.....
	3.4	3.5	4.8	3.7	3.5	2.9	2.9	2.9	2.9	1.4	3.2	.....
	3.4	3.5	4.6	3.5	3.3	3.0	3.2	2.9	2.8	1.4	.....	.....
	3.5	10.5	4.2	3.3	3.3	3.0	3.0	2.9	2.7	1.3	.....	.....
	3.4	8.7	4.0	3.3	3.3	2.9	3.0	2.9	2.6	1.3	.....	.....
	3.4	6.2	4.2	3.3	3.0	2.9	3.0	2.9	2.8	1.5	.....	.....
	3.3	5.1	4.1	3.2	3.0	3.0	3.0	2.9	3.0	1.6	.....	.....
	3.3	4.5	4.0	3.1	3.0	2.9	2.9	3.0	3.0	1.6	.....	.....
	3.3	4.3	3.9	3.0	3.0	2.9	3.2	3.0	2.9	1.7	.....	.....
	3.3	4.0	3.8	3.0	3.0	2.9	3.1	3.0	2.8	1.7	.....	.....
	3.3	.....	3.7	3.0	2.9	2.9	3.1	2.9	2.8	2.4	.....	.....
	3.3	.....	3.6	2.9	2.9	2.8	3.1	2.8	2.7	2.7	.....	.....
	3.3	.....	3.6	.....	2.9	.....	3.0	2.6	.....	2.7	.....	.....

Rating table for North Branch of Potomac River at Cumberland, Md., from June 11, 1894, to November 20, 1897.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.65	0	3.70	1,420	4.80	4,280	5.90	7,590
2.70	7	3.80	1,650	4.90	4,570	6.00	7,900
2.80	50	3.90	1,890	5.00	4,860	6.50	9,500
2.90	135	4.00	2,130	5.10	5,150	7.00	11,150
3.00	235	4.10	2,380	5.20	5,450	7.50	12,850
3.10	350	4.20	2,640	5.30	5,750	8.00	14,600
3.20	480	4.30	2,900	5.40	6,050	8.50	16,400
3.30	630	4.40	3,170	5.50	6,350	9.00	18,250
3.40	800	4.50	3,440	5.60	6,660	9.50	20,150
3.50	990	4.60	3,720	5.70	6,970	10.00	22,100
3.60	1,200	4.70	4,000	5.80	7,280	10.50	24,100

[a] This table is strictly applicable only for open-channel conditions. It is based on 20 discharge measurements made during 1895–1898. It is fairly well defined between gage heights 3.0 feet and 5.5 feet. Below 3.0 feet it is uncertain. The extension above 5.5 feet is probably fairly accurate.

Estimated monthly discharge of North Branch of Potomac River at Cumberland, Md.[a]

Month.	Discharge in second-feet.			Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.
1894.				1896.			
June 11–30	960	350	632	January	2,640	135	357
July	235	0	56.5	February	4,570	350	1,426
August	350	0	77.5	March	14,600	235	2,024
September	480	0	63.8	April	4,860	630	1,709
October	235	0	47.0	May	3,440	135	1,275
November	990	0	323	June	2,360	480	927
December	4,000	135	547	July	22,100	135	2,224
				August	1,650	50	308
1895.				September	22,100	0	916
January	7,900	235	1,069	October	6,350	135	820
February	4,860	630	1,099	November	6,350	350	1,073
March	7,900	1,420	3,094	December	1,420	350	627
April	6,660	480	1,810				
May	1,650	350	853	The year	22,100	0	1,162
June	630	50	267				
July	1,420	7	348	1897.			
August	50	0	2.5	January	2,130	480	801
September	0	0	0	February	24,100	800	3,770
October	0	0	0	March	7,900	1,200	2,704
November	0	0	0	April	6,050	135	1,554
December	480	0	71.3	May	12,850	135	2,156
				June	235	0	103
The year	7,900	0	768	July	480	0	132
				August	990	0	215
				September	480	0	55.6
				October	7	0	.45
				November 1–20	2,130	50	572

[a] These estimates do not include flow in canal feeders.

ISCELLANEOUS DISCHARGE MEASUREMENTS IN NORTH BRANCH OF POTOMAC RIVER BASIN.

The following miscellaneous discharge measurements have been ıde in the basin of North Branch of Potomac River:

iscellaneous discharge measurements in North Branch of Potomac River drainage basin.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Square feet.*	*Feet per sec.*	*Second-feet.*
t. 24, 1897	Buffalo Creek.....	At mouth near Bayard, W. Va.	15	12	1.92	[a] 23
t. 23, 1897	North Branch of Potomac River.	Near Gormania, W. Va	61	74	.73	54
r 17, 1905	....do.....	.....do.....	67	65	.58	38
r 16, 1905	Difficult Creek.....	At mouth, 4 miles below Gormania, W. Va.	12	9	1.11	10
t. 25, 1897	Stony River.....	200 yards above mouth near Schell, W. Va.	29	30	1.27	38
r. 16, 1905	.....do.....	500 feet above bridge near Gormania, W. Va.	45	57	1.37	78
t 25, 1897	North Branch of Potomac River.	200 yards above mouth of Laurel Run near Schell, W. Va.	44	100	1.36	136
t. 25, 1897	Abram Creek.....	100 yards above railroad bridge near Harrison, W. Va.	13	19	.39	7.4
t. 27, 1897	North Branch of Potomac River.	100 yards above mouth of Savage River near Bloomington, Md.	36	62	1.97	122
. 27, 1897	.....do.....	Above mouth of Savage River and below Baltimore and Ohio R. R. bridge near Bloomington, Md.	45	64	1.59	102
t. 27 1897	Savage River.....	Above junction with North Branch of Potomac River near Bloomington, Md.	20	7.5	.93	[b] 7
. 27, 1897	.....do.....	½ mile above mouth and above Piedmont water supply intake near Bloomington, Md.	13	12	.92	11
t. 28, 1897	Georges Creek.....	At Cumberland and Pennsylvania R. R. bridge, Westernport, Md.	9	13	.46	6
t. 29 1897	New Creek.....	150 yards above mouth near Keyser, W. Va.	9	4.9	.71	[a] 3.5
. 28, 1897	North Branch of Potomac River.	Near Twenty-first, Md.....	80	110	1.15	126
. 28 1897	.....do.....	Near Gerstell, Md.....	187	268	.52	138
t. 28, 1897	Wills Creek.....	Above paper mill near Cumberland, Md.	22	10	1.20	12
r 12, 1898	.....do.....	Pulp-mill bridge, Cumberland, Md.	86	262	1.45	381
r 13, 1898	.....do.....	.....do.....	86	262	1.40	368
r 18, 1905	Town Drain.....	Mechanics street bridge, Cumberland, Md.	20	12	1.50	[b] 18
t. 25, 1897	Evitts Creek.....	200 yards above railroad near Cumberland, Md.	12	9	2.33	21
t. 28, 1897	Patterson Creek.....	Baltimore and Ohio R. R bridge near Patterson Depot, W. Va.	14	5	2.40	12

Increased discharge caused by rain Sept. 23, 1897.
Discharge does not include Piedmont water supply.
Discharge does not include water pumped to Baltimore and Ohio R. R. car shops and two mills ere it is used for boiler feed. Creek stated to be exceptionally low.
Measured at 7 a. m., when flow was largely house sewage.

SOUTH BRANCH OF POTOMAC RIVER BASIN.

GENERAL DESCRIPTION.[a]

The bed of South Branch of the Potomac is mostly coarse gravel, the banks are of loose sediment, and on account of the sudden and local swells to which the river is subject the channel is continually changing. At no places are there falls of any magnitude. The slope of the stream is as follows:

Slope of South Branch of Potomac River.

Locality.	Distance from mouth.	Elevation above tide.	Distance between points.	Fall between points.	Fall per mile between points.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*
Mouth	0.0	0	29.6	127	4.3
Opposite Romney	29.6	127	24.0	151	6.3
Moorefield	53.6	278	12.0	97	8.1
Petersburg	65.6	375			

SOUTH BRANCH OF POTOMAC RIVER NEAR SPRINGFIELD, W. VA.

A gaging station was first established at the Baltimore and Ohio Railroad bridge 3 miles southwest of Springfield, by C. C. Babb, June 3, 1894. The channel above and below the station is straight and the water rather swift. The banks are liable to overflow at times of high water. The bed of the stream is composed of rock and gravel and is probably permanent. A wire gage 34.00 feet long was used. April 10, 1895, the gage datum was raised 1.00 foot. The bench mark was a cross cut in a broad capstone of the lower wall of the north abutment of the bridge. Its elevation was 28.18 feet above gage datum. February 29, 1896, this station was discontinued on account of difficulty in obtaining an observer.

June 26, 1899, a station was established by E. G. Paul at an iron highway bridge one-fourth mile from Grace Station and 1½ miles southwest of Springfield. The channel of the stream at this point is curved and the current too sluggish to make satisfactory discharge measurements, and they were therefore made at the railroad bridge where the station was originally located, 1½ miles above. A wire gage was used to determine the stages of the river. February 2, 1902, the highway bridge and the gage were carried away by ice.

August 28, 1903, a station was established by E. G. Paul at the steel highway bridge 2½ miles east of Springfield. It was discontinued July 15, 1906.

The channel is straight for several hundred feet above and below the station. Both banks are liable to overflow at very high stages of

[a] Additional information relating to this basin is given on pp. 223–226.

river. The bed of the stream is of gravel and probably subject some changes in conditions of flow from time to time. The bridge s two spans of 150 feet each. During high water the river flows neath both spans, but at low stages beneath the left span only. ıere is a small island just above and also one below the station.

Discharge measurements were made from the bridge, to which the ge is attached. The initial point for soundings is the river face of e left abutment at the downstream side of the bridge.

A standard chain gage is located in the center of the left span on ıe downstream side of the bridge. The length of the chain from the ıd of the weight to the marker is 37.59 feet. The gage was read vice each day by James R. Blue. Bench mark No. 1 is a nail in a rge sycamore tree 15 feet downstream from the left approach to the idge. The nail is in the side of the tree away from the river and out 6 feet above the ground. Its elevation is 18.80 feet above gage ıtum.

The estimates given below for the station at the railroad bridge ıring 1894 to 1896 are essentially the same as previously published, ıe same rating curve being used. Some slight changes were neces- ry, however, on account of corrections made in the gage heights. estimates have heretofore been made for stages below gage height 5 feet, but the accompanying table was extended to include a dis- arge of 80 second-feet at gage height 2.0 feet (the minimum gage ight in 1895), on the assumption that the minimum discharge of 95 was the same as the minimum discharge of 1904. Comparisons 1895 and 1904 minimums at other stations in the Potomac River sin indicate that this assumption is very nearly correct. Estimates 1894 to 1896 are considered to be within 10 per cent of the true scharge for normal conditions of flow.

Estimates for the station at the highway bridge during 1899 to 02, as previously published, have been revised. Estimates for ıges between 4.0 feet and 8.0 feet are probably within 10 per ıt of the true discharge for normal conditions of flow. At gage ight 3.0 feet the probable error may be as high as 20 per cent. timates for stages above 8.0 feet are somewhat uncertain, espe- lly for the winter months, owing to occasional ice gorging and ckwater effects at this station. (See measurement made Decem- 31, 1901.) However, it is considered that the probable error is s than 25 per cent at gage height 20 feet.

Estimates of flow corrected for the effect of ice conditions during periods from 1896 to 1902 have been made. They were based on omparison of the flow at this station with the flow at other sta- ns in the Potomac River basin, and should be reasonably close.

Estimates for 1903 to 1906 are considered to be within 5 per cent of true discharge below gage height 5.0 feet. At 11.0 feet the

error may be as high as 20 per cent. They are the same as those published in the 1905 report. Estimates for 1903 to 1906 were not corrected for ice conditions.

A summary of the records gives the following results: Maximum discharge for twenty-four hours, 19,350 second-feet; minimum discharge for twenty-four hours, 78 second-feet; mean annual discharge for four years, 1,311 second-feet; mean annual rainfall for seven years, 33.94 inches.

Discharge measurements of South Branch of Potomac River near Springfield, W. Va.

Date.	Gage height.	Discharge.
1894.	*Feet.*	*Second-feet.*
May 31	4.70	1,074
1895.		
March 29	5.90	2,049
April 11	8.95	4,389
April 26	4.20	968
May 3	7.40	3,539
May 9	5.25	1,588
May 22	8.30	3,886
June 4	3.90	710
June 6	3.90	759
June 14	3.47	586
June 19	3.10	349
July 16	3.10	378
July 17	3.00	355
1896.		
August 6	4.40	1,058
November 18	3.60	634
1897.		
June 25	3.40	622
September 2	2.40	133
1899.		
June 26 [a]	4.00	617
1900.	*Feet.*	*Second-feet*
February 23 [a]	7.70	3,80
June 20 [a]	7.00	3,43
September 11 [a]		14
1901.		
July 23 [a]	4.50	92
December 31 [a]	[b]11.50	5,47
1903.		
August 29	2.20	2
1904.		
September 9	2.00	1
September 29 [c]	1.09	1
1905.		
March 29	4.48	2,2
April 24	3.02	7
June 8	3.11	7
November 6	2.30	2
1906.		
March 17 [d]	4.50	1,9
May 26	2.63	4

[a] Measurement made at railroad bridge; gage height taken from gage at highway bridge near Gra Station.
[b] Owing to ice jam below the station, this gage height is about 2.6 feet higher than for normal cond tions of flow.
[c] By wading below station.
[d] Discharge may be small on account of ice about the meter pivot.

Daily gage height, in feet, of South Branch of Potomac River near Springfield, W. Va

Day.	June.	July.	Aug.	Sept.	Oct.	Day.	June.	July.	Aug.	Sept.	Oc
1894. [a]						1894. [a]					
1	.....	3.1	3.2	2.7	2.6	17	3.6	.....	2.5	2.6	3
2	.....	3.1	3.1	2.7	4.1	18	3.65	.....	2.5	3.6	3
3	4.4	3.1	2.8	2.6	3.8	19	3.9	.....	2.8	5.7	3
4	4.2	3.0	2.8	2.6	3.5	20	4.2	.....	2.7	5.1	3
5	4.1	3.0	2.7	2.6	3.3	21	3.65	.....	2.7	4.0	....
6	4.0	3.0	2.6	2.6	3.1	22	3.6	2.6	2.65	3.6	....
7	4.5	3.0	2.5	2.5	3.0	23	3.5	3.0	2.6	3.3	....
8	5.4	3.0	2.5	3.0	2.9	24	3.4	3.0	2.6	3.1	....
9	5.0	3.0	2.5	3.0	2.9	25	3.4	2.9	2.6	3.1	....
10	4.7	2.9	2.5	2.9	2.8	26	3.3	2.8	2.6	3.0	....
11	4.3	2.8	2.5	2.8	4.2	27	3.4	2.8	2.6	2.9	....
12	4.1	2.8	2.5	2.8	4.1	28	3.4	2.8	2.7	2.9	....
13	3.9	2.8	3.0	2.7	3.8	29	3.25	2.8	2.7	2.7	....
14	3.85	2.7	2.8	2.7	3.6	30	3.2	2.7	2.7	2.6	....
15	3.8	.....	2.7	2.6	3.5	31	.....	3.8	2.7	.....	....
16	3.8	.....	2.6	2.6	3.4						

[a] 1894 gage heights have been reduced 1.00 foot to the new datum established April 10, 1895.

Daily gage height, in feet, of South Branch of Potomac River near Springfield, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1895.												
1					7.7	4.4	4.8	3.1	2.5	2.0	2.5	2.5
2					7.0	4.2	4.5	3.0	2.4	2.0	2.4	2.4
3					6.8	4.0	4.2	3.0	2.4	2.0	2.4	2.3
4					6.8	3.9	4.0	2.9	2.3	2.0	2.3	2.3
5					(a)	3.8	3.8	2.7	2.3	2.0	2.5	2.3
6						4.2	4.2	2.8	2.3	2.0	2.4	2.3
7						3.9	3.9	2.7	2.3	2.0	2.4	2.3
8						3.8	3.5	2.7	.....	2.0	2.4	2.3
9					5.2	3.7	3.9	2.7	.....	2.0	2.4	2.4
10					5.4	3.5	3.6	2.7	.....	2.0	2.5	2.4
11				8.95	5.1	3.4	3.4	2.7	.....	2.0	2.4	2.4
12				7.5	5.7	3.4	3.3	2.7	.....	2.0	2.3	2.4
13				7.0	6.8	3.3	3.1	2.6	.....	2.0	2.3	2.4
14				6.6	6.2	3.5	3.0	2.6	.....	2.0	2.2	2.4
15				6.4	6.2	3.5	3.3	2.6	.....	2.0	2.2	2.4
16				6.1	6.0	3.4	3.1	2.6	.....	2.0	2.3	2.3
17				5.9	5.9	3.4	2.9	2.6	.....	2.0	2.3	2.3
18				5.6	6.2	3.3	2.9	2.6	.....	2.0	2.3	2.3
19				5.4	6.4	3.2	2.8	2.6	.....	2.0	2.3	2.3
20				5.2	6.0	3.1	2.8	2.6	.....	2.0	2.3	2.3
21				5.0	5.8	3.0	2.8	2.5	.....	2.0	2.3	2.6
22				4.7	7.9	2.9	2.7	2.5	.....	2.0	2.3	4.9
23				4.6	7.6	2.9	3.0	2.5	2.0	2.0	2.3	4.3
24				4.5	6.6	2.8	3.2	2.5	2.0	2.1	2.3	4.0
25				4.4	6.2	3.0	3.2	2.4	2.0	2.1	2.3	.....
26				4.2	5.8	3.2	3.3	2.4	2.0	2.0	2.3	3.4
27				4.15	5.5	4.4	3.4	2.3	2.0	2.0	2.3	3.2
28				4.0	5.4	4.0	3.2	2.3	2.0	2.0	2.3	3.0
29				4.2	5.0	3.7	3.0	2.3	2.0	2.0	2.5	2.8
30				4.9	4.7	3.5	2.9	2.3	2.0	2.1	2.6	3.2
31				.....	4.5	.....	2.9	2.6	.....	2.1	.....	3.9

Day.	Jan.	Feb.	Day.	Jan.	Feb.	Day.	Jan.	Feb.
1896.b			1896.b			1896.b		
1	5.0	4.0	12	.....	5.3	23	3.0	4.0
2	4.7	4.6	13	.....	5.7	24	3.6	3.9
3	4.1	6.9	14	.....	9.1	25	6.9	3.9
4	4.0	7.85	15	.....	8.3			
5	.....	7.1				26	6.2	3.7
			16	.....	7.2	27	5.0	3.7
6	.....	6.3	17	.....	5.5	28	4.5	3.5
7	.....	9.4	18	.....	5.3	29	4.2	3.4
8	.....	8.6	19	.....	4.7	30	3.9	.....
9	.....	7.4	20	.....	4.4	31	3.8	.....
10	.....	6.0	21	.....	5.1			
11	.....	5.5	22	.....	6.2			

a Repairing bridge; record lost May 5–8, 1895.
b River frozen January 4–23, 1896.

Daily gage height, in feet, of South Branch of Potomac River near Springfield, W. Va. Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	I
1899.[a]												
1.							3.2	3.4	3.4	3.4	4.6	
2.							3.7	3.6	3.4	3.4	4.8	
3.							3.7	3.5	3.5	3.4	4.8	
4.							3.7	3.4	3.6	3.3	4.8	
5.							3.6	3.2	3.6	3.3	4.6	
6.							3.6	3.2	3.6	3.2	4.6	
7.							3.6	3.2	3.5	3.2	4.5	
8.							3.7	3.2	3.5	3.2	4.4	
9.							4.2	3.1	3.5	3.2	4.2	
10.							3.9	3.1	3.5	3.2	4.1	
11.							3.8	3.1	3.4	3.1	4.1	
12.							3.6	3.0	3.4	3.1	4.0	
13.							3.4	3.0	3.4	3.1	4.0	
14.							3.2	3.1	3.4	3.2	4.0	
15.							3.1	3.2	3.5	3.2	3.9	
16.							3.0	3.2	3.5	3.2	3.8	
17.							2.9	3.1	3.5	3.2	3.7	
18.							3.0	3.1	3.4	3.2	3.6	
19.							3.4	3.0	3.4	3.1	3.6	
20.							3.2	3.0	3.4	3.1	3.9	
21.							3.2	3.1	3.3	3.1	4.9	
22.							3.2	3.2	3.3	3.1	5.9	
23.							3.4	3.2	3.2	3.0	5.8	
24.							3.5	3.3	3.1	3.0	5.6	
25.							3.5	3.3	3.1	3.2	5.6	
26.						4.0	3.4	3.2	3.0	3.4	5.4	
27.						4.2	3.4	3.2	3.0	3.5	5.2	
28.						3.9	3.2	3.1	3.2	3.5	4.8	
29.						4.1	3.2	3.1	3.3	3.8	4.7	
30.						3.4	3.2	3.2	3.4	4.2	4.6	
31.							3.2	3.2		4.4		
1900.[b]												
1.			9.8	7.4	4.4	4.0	5.0	3.6	3.5	4.0	3.6	
2.			8.4	7.0	4.3	4.8	5.0	3.4	3.4	3.8	3.6	
3.			6.8	6.5	4.2	4.4	5.0	3.4	3.4	3.7	3.6	
4.			6.8	5.6	4.2	4.4	5.2	3.4	3.4	3.5	4.0	
5.			6.4	5.2	4.1	4.2	5.2	3.4	3.3	3.4	4.0	
6.			6.2	5.2	4.1	4.2	5.0	3.2	3.3	3.4	3.8	
7.			7.0	5.0	4.1	4.1	5.0	3.2	3.2	3.6	3.8	
8.			7.8	5.0	4.0	4.0	4.7	3.2	3.1	3.6	3.6	
9.			9.4	4.8	4.0	4.0	4.4	3.1	3.8	3.5	3.6	
10.		5.8	6.0	4.6	4.0	4.0	4.4	3.0	4.5	3.5	3.6	
11.		6.0	7.4	4.2	4.0	3.9	4.2	3.0	4.0	3.5	3.5	
12.		6.4	6.8	4.2	3.9	3.9	4.0	3.0	4.0	3.3	3.4	
13.		6.4	6.2	4.0	3.8	3.9	3.6	3.0	3.6	3.2	3.8	
14.		6.8	5.7	4.0	3.8	5.6	3.2	3.0	3.4	3.2	3.2	
15.		7.2	5.4	3.8	3.7	5.2	3.2	3.0	3.0	3.8	3.2	
16.	4.2	7.0	5.0	3.5	3.6	7.65	3.2	2.9	3.0	3.7	3.1	
17.	4.6	6.8	4.8	3.4	3.6	13.0	3.1	2.9	2.9	3.6	3.1	
18.	4.8		4.6	3.4	3.6	10.2	3.1	2.9	2.9	3.6	3.1	
19.	4.9		5.0	3.2	3.5	9.5	3.0	2.9	2.9	3.6	3.4	
20.	5.0		7.8	4.4	4.0	7.0	3.0	2.9	2.8	3.5	3.4	
21.	9.0		11.4	5.6	3.7	5.4	3.0	2.8	2.8	3.5	3.6	
22.	7.0	6.4	10.8	6.0	3.5	5.1	3.4	3.2	2.8	3.5	3.8	
23.	6.8	7.7	9.2	6.8	3.4	5.0	3.6	3.4	3.0	3.5	3.8	
24.	6.2	7.4	8.4	6.2	3.4	4.9	3.8	3.4	3.0	3.4	3.8	
25.	5.6		7.6	6.0	3.2	4.9	3.8	3.4	3.0	3.2	4.0	
26.	5.2		6.5	5.6	3.1	5.2	4.6	4.2	3.0	3.2	10.2	
27.			6.4	5.2	3.4	5.4	5.0	4.0	3.0	3.2	12.0	
28.			6.1	5.0	3.4	5.6	5.4	4.0	3.4	3.2	9.8	
29.			6.8	4.7	3.5	5.6	5.4	3.8	3.5	3.2	8.2	
30.			7.4	4.4	3.6	5.4	4.5	3.6	4.0	3.4	6.8	
31.			7.8		4.0		4.0	3.5		3.5		

[a] Ice conditions December 25–31, 1899.

[b] Ice conditions January 1–15, January 27 to February 9, February 18–21, 25–28, and December 17–1900.

gage height, in feet, of South Branch of Potomac River near Springfield, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.[a]												
	3.4			4.8	5.8	7.6	5.0	3.6	7.25	4.0	3.2	3.4
	3.4			4.5	5.6	6.8	5.0	3.4	4.6	4.2	3.4	3.4
			3.8	4.2	5.4	6.2	5.4	3.1	4.4	4.6	3.4	3.4
		4.0	3.8	8.2	5.5	5.8	5.6	3.1	4.4	3.8	3.3	7.0
		4.0	5.0	8.6	5.0	5.8	5.6	3.1	4.2	3.6	3.3	6.4
				9.4	4.9	6.0	5.3	3.6	4.2	3.6	3.2	6.0
			4.5	8.6	4.5	6.4	5.8	4.2	4.1	3.5	3.2	
			4.6	8.0	4.8	6.2	5.8	4.0	4.1	3.5	3.2	4.8
	3.6		4.8	7.6	6.1	5.4	5.4	3.6	4.1	3.5	3.2	4.6
	3.6		4.8	6.8	16.5	5.0	5.0	3.2	4.0	3.4	3.2	4.5
	3.8		12.2	6.4	12.1	4.8	4.8	3.8	4.0	3.4	3.1	4.5
	7.6		11.4	5.8	8.2	4.5	4.2	3.8	4.0	3.4	3.1	4.5
	9.2		9.4	5.6	7.4	4.4	4.0	3.6	5.2	3.3	3.1	4.8
	8.0		8.2	6.4	6.5	5.3	4.0	3.6	5.4	3.3	3.1	5.0
	6.4		7.4	11.2	6.0	5.6	6.0	3.5	5.0	3.2	3.1	20.0
	5.6		6.0	10.0	5.8	12.4	6.2	3.5	4.4	3.2	3.1	15.0
	5.4		5.8	9.2	5.6	10.2	6.5	3.4	3.8	3.2	3.1	11.2
	5.4		5.4	9.0	5.2	8.1	6.8	3.4	3.6	3.2	3.1	6.8
	5.2		5.2	8.6	5.0	7.8	5.4	3.4	3.6	3.2	3.1	5.7
			5.2	10.5	5.0	7.0	5.0	3.8	3.6	3.2	3.1	
			5.0	18.4	4.8	6.1	4.2	4.0	3.5	3.1	3.1	
			6.8	16.0	11.5	5.6	4.0	4.2	3.5	3.1	3.0	
			7.0	12.2	9.0	5.4	4.5	4.5	3.5	3.1	3.0	
	4.4		7.0	8.9	7.6	5.4	4.0	3.8	3.4	3.1	3.0	
	4.4		6.8	8.4	5.4	5.2	3.8	3.8	3.4	3.1	5.2	
	4.2		6.5	7.6	5.0	5.6	4.2	3.5	3.4	3.1	4.6	
	4.2		6.2	7.2	6.5	6.4	3.6	3.5	3.4	3.1	4.0	
	4.2		6.0	6.8	8.7	6.0	3.4	3.8	3.3	3.1	3.8	
			5.6	6.4	12.2	6.1	3.0	4.5	3.3	3.1	3.7	8.6
			5.4	6.0	11.6	5.0	3.0	4.5	3.2	3.1	3.5	14.6
			5.2		8.4		3.4	4.4		3.1		12.2

Day.	Jan.	Day.	Jan.	Day.	Jan.	Day.	Jan.
1902.[b]		1902.[b]		1902.[b]		1902.[b]	
	8.2	10	8.6	18		25	
	6.8			19			
	6.4	11	5.6	20		26	
	6.0	12	4.5			27	5.2
		13		21		28	7.6
		14		22		29	7.8
		15		23		30	
				24		31	
		16					
	8.8	17					

[a] conditions January 3–8, 20–23, January 29 to February 3, February 6 to March 2, March 6, December 20–28, 1901.

[b] conditions January 5–8, 13–26, and January 30 to February 24, 1902. Bridge and gage carried away by flood February 24, 1902.

Daily gage height, in feet, of South Branch of Potomac River near Springfield, W. Va.—Continued.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.[a]					
1	.....	2.75	2.2	2.2	2.2
2	.....	2.7	2.2	2.2	2.1
3	.....	2.6	2.2	2.2	2.1
4	.....	2.55	2.2	2.2	2.2
5	.....	2.45	2.2	2.2	2.1
6	.....	2.4	2.2	2.2	2.1
7	.....	2.3	2.1	2.2	2.1
8	.....	2.3	2.3	2.2	2.15
9	.....	2.3	2.6	2.2	2.15
10	.....	2.55	2.6	2.2	2.2
11	.....	2.45	2.6	2.1	2.25
12	.....	2.45	2.6	2.1	2.4
13	.....	2.3	2.5	2.1	2.2
14	.....	2.3	2.4	2.1	2.25
15	.....	2.25	2.4	2.1	2.5
16	.....	2.2	2.4	2.1	2.5
17	.....	2.25	2.4	2.2	2.3
18	.....	2.45	2.4	2.2	2.3
19	.....	3.0	.....	2.2	2.3
20	.....	2.85	.....	2.3	2.1
21	.....	2.65	.....	2.3	2.2
22	.....	2.5	.....	2.3	2.4
23	.....	2.45	.....	2.2	2.6
24	.....	2.4	.....	2.2	2.4
25	.....	2.35	2.2	2.2	2.3
26	.....	2.25	2.2	2.2	2.3
27	.....	2.2	2.2	2.2	2.6
28	2.2	2.2	2.2	2.2	2.6
29	2.2	2.2	2.2	2.2	2.6
30	2.55	2.2	2.2	2.2	2.6
31	2.8	.....	2.2	.....	2.6

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.[b]												
1	2.6	2.8	3.75	3.65	5.4	3.45	2.8	2.4	2.0	1.8	1.8	1.9
2	2.6	2.8	4.6	4.05	4.85	3.5	2.65	2.5	2.0	1.8	1.8	1.9
3	2.6	2.8	4.2	3.95	4.35	3.45	2.6	2.7	2.0	1.8	1.8	1.9
4	2.6	2.7	4.35	3.7	4.15	3.4	2.6	2.8	2.0	1.8	1.8	1.9
5	2.6	2.6	4.1	3.5	3.9	4.35	2.6	2.8	2.0	1.8	1.8	1.
6	2.6	2.6	3.65	3.35	3.65	4.3	2.5	2.6	2.0	1.85	1.8	1.
7	2.6	3.0	3.45	3.2	3.3	3.9	2.5	2.6	2.0	1.85	1.8	1.
8	2.6	6.4	5.55	3.2	3.5	3.8	2.6	2.55	2.0	1.8	1.8	1.
9	2.6	4.85	5.6	3.15	3.4	3.35	2.5	2.5	2.1	1.8	1.8	1.
10	2.6	3.55	4.6	3.2	3.6	3.1	2.85	2.4	2.15	1.8	1.9	2.
11	2.6	3.2	4.05	3.3	3.4	2.95	4.5	2.3	2.1	1.8	1.9	2.
12	2.6	2.7	3.85	3.25	3.25	3.1	3.85	2.25	2.1	1.8	1.9	2.
13	2.6	2.85	3.65	3.2	3.1	3.1	3.5	2.2	2.1	1.8	1.9	2.
14	2.6	2.95	3.5	3.2	3.0	3.0	2.95	2.1	2.2	1.8	1.9	2.
15	2.6	3.05	3.35	3.0	3.0	2.7	2.85	2.1	2.15	1.8	1.9	2.
16	2.6	2.95	3.15	2.85	3.0	2.95	2.55	2.1	2.05	1.8	1.9	2.
17	2.6	2.9	3.1	2.8	3.0	2.85	2.45	2.0	2.0	1.8	1.8	2.
18	2.6	2.65	3.1	3.0	3.25	3.1	2.5	2.0	2.0	1.8	1.8	2.
19	2.6	2.95	3.1	3.0	8.05	3.0	2.55	2.0	2.0	1.8	1.8	2.
20	2.6	2.9	3.05	3.0	7.95	5.65	2.6	2.0	1.9	1.8	1.8	2.
21	2.6	2.95	3.05	3.0	6.3	4.7	2.7	2.0	1.9	1.9	1.8	2.1
22	2.85	3.5	3.4	2.9	5.4	3.95	2.6	2.0	1.9	1.9	1.8	2.1
23	9.05	4.5	3.9	2.8	4.8	3.6	2.8	2.0	1.9	1.9	1.8	2.1
24	5.4	4.05	4.55	2.8	4.3	3.45	2.9	2.0	1.9	1.9	1.8	2.1
25	4.05	3.0	4.45	2.7	3.95	3.2	2.8	2.0	1.8	1.8	1.8	2.2
26	3.45	3.25	4.15	2.8	3.75	2.9	2.5	2.0	1.8	1.8	1.8	2.2
27	3.0	2.95	3.95	3.05	3.8	2.75	2.7	2.0	1.8	1.8	1.8	2.5
28	2.9	2.95	3.8	8.6	4.2	2.55	2.6	1.9	1.8	1.8	1.8	2.6
29	2.65	2.95	3.45	8.1	3.65	2.75	2.5	2.1	1.8	1.8	1.8	3.5
30	2.75	.....	3.45	6.6	3.45	2.9	2.4	2.1	1.8	1.8	1.8	3.9
31	2.9	.....	3.35	.....	3.45	.....	2.4	2.0	.....	1.8	.....	3.9

[a] Ice conditions December 4–31, 1903.

[b] River frozen over January 1–22, 1904; river clear January 23–27, 1904; ice conditions January 28 to February 7, 1904; river frozen over December 19–31, 1904.

age height, in feet, of South Branch of Potomac River near Springfield, W. Va.—Continued.

y.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5.[a]												
.....	2.35	2.9	4.1	3.55	2.9	2.9	3.55	2.9	2.7	2.0	2.4	2.3
.....	2.45	2.9	3.9	3.35	2.9	3.0	3.7	2.75	2.6	2.0	2.35	2.3
.....	2.3	2.9	3.8	3.3	2.8	2.95	3.45	2.6	2.5	2.0	2.3	3.2
.....	2.45	2.9	3.4	3.1	2.8	2.75	4.15	2.6	2.5	2.0	2.2	5.15
.....	2.55	2.9	3.7	3.1	2.7	2.7	3.8	2.5	2.4	2.0	2.2	4.35
.....	2.35	3.0	4.55	4.0	2.7	2.7	5.35	2.5	2.4	2.0	2.2	3.9
.....	2.3	3.0	4.9	4.7	2.7	2.7	4.35	2.65	2.3	2.0	2.2	3.5
.....	2.2	3.0	5.25	4.55	2.8	3.0	3.9	2.65	2.25	2.0	2.2	3.2
.....	2.3	3.1	7.05	4.2	2.8	2.75	3.65	2.55	2.2	2.0	2.2	3.05
.....	2.4	3.1	11.1	3.95	2.8	2.65	3.35	2.5	2.25	2.0	2.2	2.95
.....	2.4	3.1	8.75	3.9	2.8	2.6	3.4	2.85	2.45	2.0	2.2	2.85
.....	2.3	3.1	7.25	3.8	3.85	2.65	3.85	2.85	2.45	2.0	2.1	2.7
.....	4.7	3.1	6.15	3.5	7.5	2.65	4.85	2.5	2.3	2.0	2.1	2.65
.....	6.05	3.1	5.35	3.35	5.8	2.55	5.95	3.6	2.4	2.25	2.1	2.55
.....	4.75	3.1	4.9	3.3	7.55	2.45	5.6	4.4	2.45	2.2	2.1	2.45
.....	3.6	3.1	4.75	3.2	7.05	2.4	4.75	3.9	2.3	2.1	2.1	2.55
.....	3.2	3.1	4.75	3.2	5.75	2.3	3.9	3.4	2.2	2.0	2.1	2.6
.....	3.1	3.1	5.25	3.1	4.9	2.3	3.5	3.1	2.2	2.0	2.1	2.5
.....	3.15	3.1	5.55	3.0	4.3	2.3	3.25	3.0	2.1	2.0	2.1	2.4
.....	3.2	3.1	5.9	3.0	4.0	2.2	3.05	2.95	2.1	2.1	2.1	2.35
.....	3.3	3.1	7.1	2.9	3.6	2.55	3.2	2.75	2.0	2.1	2.1	6.1
.....	3.2	3.1	10.05	2.9	3.45	3.9	3.25	2.7	2.0	2.15	2.1	9.45
.....	3.2	3.1	7.55	2.9	3.25	6.0	3.95	2.6	1.9	2.25	2.1	7.75
.....	3.05	3.1	6.15	2.8	3.05	9.2	5.2	2.55	1.9	2.3	2.1	7.05
.....	3.0	3.1	7.25	2.7	2.95	8.55	4.15	4.0	1.9	2.45	2.1	6.15
.....	2.85	3.8	6.2	2.7	2.9	5.9	3.55	5.65	1.8	2.55	2.1	5.65
.....	2.7	3.9	5.4	2.8	2.8	6.85	3.3	4.2	1.8	2.9	2.1	5.2
.....	2.5	4.1	4.8	2.8	2.8	5.8	3.0	3.35	1.8	3.25	2.1	4.65
.....	3.0	.....	4.3	2.6	2.7	4.45	3.0	3.0	1.8	2.65	2.1	4.05
.....	2.9	.....	4.0	2.9	2.7	3.85	3.85	2.8	2.0	2.55	2.2	4.4
.....	2.5	.....	3.85	.....	2.6	.....	3.1	2.7	.....	2.45	.....	4.6
6.[b]												
.....	4.0	4.05	2.6	9.65	4.85	2.8	3.0	.....	.....	.....	.....	.....
.....	3.95	3.85	2.7	8.75	4.55	2.7	2.8	.....	.....	.....	.....	.....
.....	3.85	3.55	2.8	7.85	4.35	2.7	2.68	.....	.....	.....	.....	.....
.....	6.75	3.4	7.05	6.25	4.2	2.8	2.7	.....	.....	.....	.....	.....
.....	8.65	3.4	6.65	5.3	4.0	2.7	3.15	.....	.....	.....	.....	.....
.....	6.7	3.2	5.65	5.4	4.15	2.7	2.9	.....	.....	.....	.....	.....
.....	5.3	3.05	4.8	5.15	3.9	2.85	2.85	.....	.....	.....	.....	.....
.....	4.6	3.0	4.35	4.95	4.0	2.85	2.55	.....	.....	.....	.....	.....
.....	4.15	3.0	4.05	4.65	3.85	2.85	2.4	.....	.....	.....	.....	.....
.....	3.75	3.1	3.85	5.35	3.7	2.85	2.48	.....	.....	.....	.....	.....
.....	3.6	2.9	3.65	5.45	3.65	2.65	2.3	.....	.....	.....	.....	.....
.....	3.9	2.9	3.5	5.15	3.4	2.5	2.25	.....	.....	.....	.....	.....
.....	4.3	2.85	3.35	4.75	3.3	2.58	2.3	.....	.....	.....	.....	.....
.....	4.5	2.7	3.3	4.4	3.25	2.4	2.1	.....	.....	.....	.....	.....
.....	4.55	2.7	3.65	5.4	3.2	2.5	.....	.....	.....	.....	.....	.....
.....	5.15	2.7	4.25	6.6	3.4	2.7	.....	.....	.....	.....	.....	.....
.....	5.2	2.6	4.45	5.9	3.3	2.7	.....	.....	.....	.....	.....	.....
.....	4.75	2.5	4.4	5.5	3.2	2.75	.....	.....	.....	.....	.....	.....
.....	4.45	2.4	4.4	4.85	3.1	2.9	.....	.....	.....	.....	.....	.....
.....	4.05	2.4	4.8	4.45	3.0	3.0	.....	.....	.....	.....	.....	.....
.....	3.85	2.6	5.15	4.0	3.05	3.85	.....	.....	.....	.....	.....	.....
.....	3.75	2.65	5.65	3.85	2.85	4.0	.....	.....	.....	.....	.....	.....
.....	5.15	2.7	6.1	3.75	2.75	3.65	.....	.....	.....	.....	.....	.....
.....	9.5	2.6	5.95	3.65	2.7	3.35	.....	.....	.....	.....	.....	.....
.....	7.2	2.6	5.35	3.6	2.6	3.5	.....	.....	.....	.....	.....	.....
.....	5.25	2.6	5.6	6.35	2.6	4.2	.....	.....	.....	.....	.....	.....
.....	4.85	2.6	8.65	9.85	2.5	4.1	.....	.....	.....	.....	.....	.....
.....	4.65	2.6	13.55	7.3	2.6	3.45	.....	.....	.....	.....	.....	.....
.....	4.75	.....	10.85	5.75	2.7	3.05	.....	.....	.....	.....	.....	.....
.....	4.45	.....	10.65	5.05	2.65	3.0	.....	.....	.....	.....	.....	.....
.....	4.25	.....	10.95	.....	2.7	.....	.....	.....	.....	.....	.....	.....

[a] Ice conditions during portions of January and February, 1905.
[b] Flow probably unaffected by ice conditions during 1906.

Rating tables for South Branch of Potomac River, near Springfield, W. Va.

JUNE 3, 1894, TO FEBRUARY 29, 1896.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
2.00	80	2.90	300	3.80	700	5.40	1,720
2.10	96	3.00	330	3.90	750	5.60	1,860
2.20	113	3.10	360	4.00	800	5.80	2,000
2.30	132	3.20	400	4.20	910	6.00	2,145
2.40	154	3.30	450	4.40	1,030	7.00	2,895
2.50	180	3.40	500	4.60	1,160	8.00	3,645
2.60	210	3.50	550	4.80	1,300	9.00	4,395
2.70	240	3.60	600	5.00	1,440	10.00	5,145
2.80	270	3.70	650	5.20	1,580		

JUNE 26, 1899, TO JANUARY 29, 1902.[b]

2.70	85	4.00	615	5.60	1,785	8.00	4,370
2.80	110	4.10	670	5.80	1,965	8.50	4,975
2.90	140	4.20	730	6.00	2,150	9.00	5,600
3.00	170	4.30	790	6.20	2,345	10.00	6,850
3.10	205	4.40	855	6.40	2,545	11.00	8,100
3.20	240	4.50	920	6.60	2,755	12.00	9,350
3.30	280	4.60	990	6.80	2,975	13.00	10,600
3.40	320	4.70	1,060	7.00	3,200	14.00	11,850
3.50	365	4.80	1,135	7.20	3,430	15.00	13,100
3.60	410	4.90	1,210	7.40	3,660	16.00	14,350
3.70	460	5.00	1,285	7.60	3,890	18.00	16,850
3.80	510	5.20	1,445	7.80	4,130	20.00	19,350
3.90	560	5.40	1,615				

AUGUST 28, 1903, TO JULY 14, 1906.[c]

1.80	78	3.00	702	4.10	1,790	5.40	3,690
1.90	96	3.10	778	4.20	1,912	5.60	4,030
2.00	125	3.20	860	4.30	2,038	5.80	4,380
2.10	163	3.30	947	4.40	2,168	6.00	4,745
2.20	210	3.40	1,039	4.50	2,302	6.50	5,750
2.30	261	3.50	1,135	4.60	2,440	7.00	6,890
2.40	315	3.60	1,235	4.70	2,582	7.50	8,120
2.50	372	3.70	1,339	4.80	2,728	8.00	9,370
2.60	432	3.80	1,447	4.90	2,879	9.00	12,000
2.70	495	3.90	1,558	5.00	3,035	10.00	15,000
2.80	561	4.00	1,672	5.20	3,355	11.00	18,000
2.90	630						

[a] This table is strictly applicable only for open-channel conditions. It is based on discharge measurements made during 1894–1896. It is fairly well defined between gage heights 3.0 feet and 10 feet. Above gage height 5.9 feet the rating curve is a tangent, the difference being 75 per tenth.

[b] This table is strictly applicable only for open-channel conditions. It is based on four discharge measurements made during 1899–1901. It is not well defined. Above gage height 8.4 feet the rating curve is a tangent, the difference being 125 per tenth. For high stages a tangent is considered to give the best results, owing to conditions below the station, which cause a backwater effect at the gage.

[c] This table is strictly applicable only for open-channel conditions. It is based on eight discharge measurements made during 1903–1906. It is fairly well defined between gage heights 2 feet and 4.5 feet. Above 6 feet gage height the discharge is approximate.

hly discharge of South Branch of Potomac River near Springfield, W. Va.

[Drainage area, 1,440 to 1,475 square miles.][a]

	Discharge in second-feet.			Run-off.		Per cent of precipitation.	Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.		In inches.	Loss in inches.
...	1,720	400	775	0.538	0.560	.....	.....	.....
...	700	210	296	.206	.238	.....	.....	.....
...	400	180	233	.162	.187	.....	.....	.....
...	1,930	180	403	.280	.312	.....	.....	.....
...	910	210	500	.347	.258	.....	.....	.....
..	4,357	800	1,792	1.24	.922	.....	.....	.....
...	3,570	1,090	2,203	1.53	1.76	.....	.....	.....
...	1,030	270	582	.404	.451	.....	.....	.....
...	1,300	240	512	.356	.410	.....	.....	.....
...	360	132	217	.151	.174	.....	.....	.....
...	180	80	108	.075	.084	.....	.....	.....
...	96	80	82.1	.057	.066	.....	.....	.....
...	210	113	145	.101	.113	.....	.....	.....
...	1,370	132	307	.213	.246	.....	.....	.....
..	2,820	250	635	.441	.508	.....	.....	.....
...	4,695	500	2,023	1.40	1.51	.....	.....	.....
...	.....	.....	.....	.....	.....	.....	2.44	.....
...	.....	.....	.....	.....	.....	.....	3.99	.....
...	.....	.....	.....	.....	.....	.....	2.92	.....
...	.....	.....	.....	.....	.....	.....	.98	.....
...	.....	.....	.....	.....	.....	.....	5.34	.....
...	730	320	579	.399	.074	.....	[b]3.81	.....
...	730	140	337	.232	.268	9	2.86	2.59
...	410	170	238	.164	.189	5	3.46	3.27
...	410	170	314	.217	.242	6	3.98	3.74
...	855	170	293	.202	.233	14	1.63	1.40
...	2,055	410	1,001	.690	.770	71	1.09	.32
...	1,965	320	984	.679	.783	53	1.48	.70
..	.....	.....	.....	.....	.....	.....	33.98	.....
...	5,600	500	1,103	.761	.877	59	1.49	.61
...	4,010	800	1,971	1.36	1.42	51	2.79	1.37
...	8,600	990	3,497	2.41	2.78	92	3.01	.23
...	3,660	240	1,400	.966	1.08	95	1.14	.06
...	855	205	509	.351	.405	19	2.10	1.70
...	10,600	560	1,945	1.34	1.50	33	4.59	3.09
...	1,615	170	783	.540	.623	20	3.17	2.55
...	730	110	287	.198	.228	13	1.78	1.55
...	920	110	299	.206	.230	9	2.65	2.42
...	615	240	359	.248	.286	14	2.12	1.83
...	9,350	205	1,361	.939	1.05	26	4.04	2.99
...	9,350	320	1,507	1.04	1.20	67	1.80	.60
..	10,600	110	1,252	.863	11.68	38	30.68	19.00

[a] age areas are used to obtain run-off on account of changes in location of stations.
[b] erpolated July 15–21, 1894.
erpolated May 5–8, 1895.
erpolated September 8–22, 1895.
erpolated December 25, 1895.
January 4–23, 1896; discharge corrected for ice conditions, the discharge of Shenan-illville, W. Va., being used as a basis.
for complete month June, 1899.
s December 25–31, 1899; discharge corrected for this period, the daily discharges at ton, and Millvill being used as a basis.
s January 1–15, January 27 to February 9, February 18–21, 25–28, and December 17–19, corrected for these periods, the daily discharges at Piedmont, Riverton, and Mill-s a basis.

Estimated monthly discharge of South Branch of Potomac River, etc.—Continued

Month.	Discharge in second-feet.			Run-off.		Per cent of precipitation.	Precipit	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.		In inches.	I i
1901.								
January[a]	5,850	300	1,119	.772	.890	52	1.70	
February[a]	615	400	426	.294	.306	115	.27	
March[a]	9,000	400	2,423	1.67	1.92	82	2.33	
April	17,350	730	4,987	3.44	3.84	62	6.20	
May	9,000	920	3,631	2.50	2.88	44	6.54	
June	9,850	855	2,560	1.77	1.98	81	2.44	
July	2,975	170	1,185	.817	.942	32	2.92	
August	920	205	484	.334	.385	6	6.60	
September	3,488	240	721	.497	.554	27	2.02	
October	990	205	322	.222	.256	137	.19	
November	1,445	170	326	.225	.251	11	2.25	
December[a b]	19,350	320	3,326	2.29	2.64	50	5.31	
The year	19,350	170	1,792	1.24	16.84	43	38.77	
1902.								
January[c]	5,350	800	1,810	1.25	1.44	66	2.19	
February							3.83	
March							4.34	
April							2.77	
May							2.38	
June							3.67	
July							2.32	
August							2.37	
September							1.95	
October							2.84	
November							2.93	
December							3.87	
The year							35.46	
1903.								
January							2.76	
February							2.85	
March							2.98	
April							3.02	
May							3.17	
June							5.33	
July							3.79	
August 28–31	561	210	346	.235	.035		[d] 3.89	
September	702	210	336	.228	.254	13	1.91	
October[e]	432	163	271	.184	.212	8	2.78	
November	261	163	206	.140	.156	20	.79	
December[f]	463	163	286	.194	.224	55	.40	
The year							33.67	
1904.								
January[g]	12,150	432	1,009	.684	.789	48	1.66	
February[g]	5,540	432	1,004	.681	.734	74	.99	
March	4,030	740	1,451	.984	1.13	61	1.84	
April	10,930	495	1,660	1.13	1.26	51	2.45	
May	9,500	702	2,143	1.45	1.67	56	3.01	
June	4,118	402	1,121	.760	.848	16	5.47	
July	2,302	315	568	.385	.444	8	5.58	
August	561	96	238	.161	.186	10	1.95	
September	210	78	123	.083	.093	5	1.83	
October	96	78	80.9	.055	.063	5	1.14	
November	96	78	79.9	.054	.060	8	.76	
December[g]	1,558	78	296	.200	.231	9	2.64	
The year	12,150	78	814	.552	7.50	26	29.32	

[a] Ice conditions January 3–8, 20–23, January 29 to February 3, February 6 to March 2, Mar December 7, 20–28, 1901. Discharge corrected for these periods, the daily discharge at Piedmont. erton, and Millville being used as a basis.

[b] There was backwater at the gage December 29–31, 1901, owing to an ice jam, but since the disch when applied to the gage heights as observed is relatively small as compared with that at Rive and Millville, it was considered best to allow them to stand without reduction for backwater effe

[c] Ice conditions January 5–8, 13–26, and January 30 to February 24, 1902. Discharge corrected January, the daily discharges at Piedmont, Riverton, and Millville being used as a basis.

[d] Precipitation for complete month August, 1903.

[e] Discharge interpolated October 19–24, 1903.

[f] Ice conditions December 4–31, 1903. No correction made in estimates.

[g] Ice conditions Jan. 1 to 22, Jan. 28 to Feb. 7, and December 19–31, 1904; no correction made in mates.

Estimated monthly discharge of South Branch of Potomac River, etc.—Continued.

Month.	Discharge in second-feet.			Run-off.		Per cent of precipitation.	Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.		In inches.	Loss in inches.
1905.								
nuary[a]	4,840	210	821	.557	.642	27	2.34	1.70
bruary[a]	1,790	630	831	.563	.586	48	1.22	.63
arch	18,300	1,039	4,793	3.25	3.75	162	2.32	−1.43
pril	2,582	432	1,015	.688	.768	63	1.23	.46
ay	8,245	432	1,744	1.18	1.36	37	3.64	2.28
ne	12,600	210	1,948	1.32	1.47	25	5.78	4.31
ly	4,652	702	1,673	1.13	1.30	21	6.26	4.96
igust	4,118	372	854	.579	.668	14	4.63	3.96
ptember	495	78	228	.155	.173	15	1.12	.95
tober	904	125	229	.155	.179	6	3.02	2.84
vember	315	163	190	.129	.144	13	1.10	.96
cember	13,350	261	2,298	1.56	1.80	59	3.06	1.26
The year	18,300	78	1,385	.939	12.84	36	35.72	22.88
1906.								
nuary	13,500	1,235	3,321	2.26	2.61			
bruary	1,731	315	664	.452	.471			
arch	25,650	432	5,076	3.45	3.98			
pril	14,550	1,235	4,538	3.09	3.45			
ay	2,804	372	1,085	.738	.851			
ne	1,912	315	770	.524	.585			
ly 1–14	819	163	449	.305	.159			

[a] Ice conditions January and February, 1905; no correction made in estimates.

MISCELLANEOUS DISCHARGE MEASUREMENTS IN SOUTH BRANCH OF POTOMAC RIVER BASIN.

The following miscellaneous discharge measurements have been made in the basin of South Branch of Potomac River:

Miscellaneous discharge measurements in South Branch of Potomac River drainage basin.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Ft. per second.*	*Second-feet.*
September 24	North Fork of South Branch of Potomac River.	500 feet above mouth near Petersburg, W. Va.	38	33	0.52	17
Do	South Branch of Potomac River.	300 yards above mouth of North Fork, near Petersburg, W. Va.	80	58	1.65	96
Do	South Fork of South Branch of Potomac River.	Near Moorefield, W. Va	24	23	1.48	34
September 26	Mill Creek	Near mouth near Romney W. Va.				3
Do	South Branch of Potomac River.	A short distance above Romney bridge near Romney, W. Va.	65	91	2.25	205

POTOMAC RIVER BASIN BETWEEN MOUTH OF SOUTH BRANCH AND SHENANDOAH RIVER.

POTOMAC RIVER AT GREAT CACAPON, W. VA.

Gage-height records were obtained of Potomac River at Dam No. 6 of the Chesapeake and Ohio Canal near Great Cacapon, from June 21, 1894, to March 7, 1896. The gage was located above the dam. Discharge measurements were made of the main river and also of the canal feeder by wading at a point about 1,000 feet below the diversion dam. The channel at this point is rocky and the current swift. The crest of the dam is not level and no data are available for determining the point on the gage at which zero flow over the dam occurs. No estimates of discharge have been made, as the number of measurements is insufficient. The gage heights are not considered of enough value for republication.

Discharge measurements of Potomac River at Great Cacapon, W. Va.

Date.	Gage height.	Discharge of river.	Discharge of canal feeder.
1895.	*Feet.*	*Second-feet.*	*Second-feet.*
June 20[a]	[b] 0.90	331	[c]
July 18	.90	543	[d] 164
August 26	— .50	132	[e] 92

[a] No water flowing over the West Virginia end of the dam for about one-eighth of the total length.
[b] Gage height not considered accurate.
[c] Water flowing in feeder, but no measurement made.
[d] Feeder gate open 3.0 feet.
[e] Feeder gate wide open.

OPEQUON CREEK NEAR MARTINSBURG, W. VA.[a]

The gaging station was established May 8, 1905, and was discontinued July 16, 1906. It is located at the highway bridge known as "Rileys Ford Bridge," about 4 miles southeast of Martinsburg, W. Va.

The channel is straight for about 300 feet above and below the station. The current is swift. Both banks are clean. The right bank is high and does not overflow. The left bank has a flood plain extending 600 feet across a level meadow. The bed of the stream is rocky, very rough, free from vegetation, and permanent. There is but one channel at ordinary stages. The stream is liable to extreme fluctuations at high water, covering the entire flood plain on the west.

Discharge measurements were made from the downstream side of the steel bridge to which the gage is attached. The initial point for soundings is the top face of the left abutment, downstream side.

A standard chain gage is fastened to the downstream side of the bridge near the left abutment. The length of the chain from the end of the weight to the marker is 19.90 feet. The gage was read twice

[a] General description of this basin is given on p. 230.

h day by Frank Mose. Bench mark No. 1 is a cross chiseled on the stream left abutment. Its elevation is 18.44 feet above the datum the gage. Bench mark No. 2 is the top of the pulley wheel of the ge. Its elevation was 19.55 feet above the datum of the gage rch 18, 1906.

Low-water measurements at this station plot very erratically, and ce the section at the gaging station has remained unchanged it is umed that the trouble lies with the controlling point below the ge. This assumption is borne out by the fact that it is known that use matter is thrown into the creek from the bridge and collects on bar a short distance below. It has seemed best to determine the charge by means of three rating curves of the same general form. Estimates based on the first two curves may be 10 to 20 per cent in or. Estimates based on the third curve are probably within 5 to 10 r cent of the true flow for normal conditions. The 1905–6 estimates e not affected by ice conditions.

Discharge measurements of Opequon Creek near Martinsburg, W. Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
y 7	1.33	141	April 2	3.32	600
vember 8	1.25	63	April 12	2.57	338
1906.			Do	2.56	332
rch 18	1.51	137	May 29	1.57	152

Daily gage height, in feet, of Opequon Creek near Martinsburg, W. Va.

Day.	May.	June.	Oct.	Nov.	Dec.	Day.	May.	June.	Oct.	Nov.	Dec.
1905						1905.					
		1.32		1.2	1.28	17	1.52		1.1	1.5	1.35
		1.28		1.18	1.2	18	1.42		1.3	1.1	1.38
		1.22		1.15	2.45	19	1.38		1.	1.1	1.22
		1.2		1.12	2.52	20	1.32		1.38	1.1	1.2
				1.	1.78						
						21	1.28		1.32	1.	7.62
				1.	1.38	22	1.25		1.25		7.3
				1.	1.3	23	1.25		1.18	1.	3.8
			1.15	1.15	1.28	24	1.22		1.12	1.	2.92
	1.35		1.12	1.12	1.25	25	1.18		1.18	1.	2.5
	1.38		1.1	1.	1.22						
						26	1.15		2.0	1.	2.18
	1.38		1.2	1.12	1.2	27	1.18		1.68	1.	2.2
	1.38		1.28	1.5	1.2	28	1.2		1.42	1.1	1.8
	1.32		1.22	1.5	1.2	29	1.18		1.38	1.5	3.1
	1.4		1.18	1.5	1.18	30	1.15		1.3	1.52	2.55
	1.98		1.12	1.5	1.15	31	1.22		1.22		2.0
	1.72		1.1	1.5	1.22						

Daily gage height, in feet, of Opequon Creek near Martinsburg, W. Va.—Continued

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	D
1906.												
1	1.73	1.6	1.26	4.72	1.92	1.5	1.7					
2	1.65	1.6	1.4	3.48	1.9	1.48	1.55					
3	1.77	1.55	1.56	3.0	1.88	1.45	1.9					
4	8.73	1.48	3.24	2.72	1.85	1.42	7.9					
5	4.2	1.45	2.4	2.55	1.82	1.4	2.88					
6	3.12	1.4	1.9	2.45	1.8	2.92	2.4					
7	2.68	1.37	1.84	2.32	1.78	2.18	2.4					
8	2.27	1.33	1.8	2.22	1.75	1.58	1.88					
9	2.15	1.32	1.72	2.48	1.72	1.58	1.78					
10	1.98	1.37	1.6	4.02	1.68	1.62	1.72					
11	1.92	1.4	1.52	3.02	1.65	1.48	1.68					
12	1.9	1.4	1.48	2.48	1.65	1.42	1.62					
13	1.98	1.4	1.48	2.25	1.62	1.48	1.6					
14	2.17	1.45	1.5	2.18	1.6	1.58	1.58					
15	2.7	1.48	1.52	8.5	1.58	1.52	1.52					
16	2.58	1.42	1.52	5.0	1.55	1.48						
17	2.25	1.4	1.52	3.28	1.52	5.38						
18	2.32	1.4	1.58	2.9	1.5	3.0						
19	1.98	1.4	1.72	2.62	1.5	2.75						
20	1.85	1.38	1.83	2.45	1.5	2.48						
21	1.78	1.37	1.82	2.35	1.48	5.18						
22	1.72	1.48	1.92	2.28	1.45	5.0						
23	1.75	1.42	2.28	2.22	1.45	2.58						
24	1.93	1.38	2.3	2.15	1.42	2.35						
25	1.85	1.35	2.35	2.1	1.4	2.18						
26	1.8	1.32	2.78	2.3	1.4	2.05						
27	1.75	1.3	4.0	2.25	1.42	1.88						
28	1.7	1.28	7.52	2.0	1.52	1.82						
29	1.67		5.45	1.98	1.52	2.08						
30	1.65		5.78	1.95	1.48	1.85						
31	1.63		7.2		1.4							

Rating tables for Opequon Creek near Martinsburg, W. Va.

MAY 9 TO JUNE 4, 1905.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.15	116	1.40	152	1.70	200	1.90	237
1.20	123	1.50	167	1.80	218	2.00	257
1.30	137	1.60	183				

OCTOBER 8 TO DECEMBER 20, 1905.[b]

1.10	50	1.50	88	1.90	140	2.30	205
1.20	58	1.60	100	2.00	155	2.40	223
1.30	67	1.70	113	2.10	171	2.50	242
1.40	77	1.80	126	2.20	188		

DECEMBER 21, 1905, TO JULY 15, 1906.[c]

1.20	97	2.20	251	3.20	549	4.40	1,092
1.30	109	2.30	271	3.30	589	4.60	1,193
1.40	122	2.40	293	3.40	630	4.80	1,295
1.50	135	2.50	317	3.50	672	5.00	1,399
1.60	149	2.60	343	3.60	715	5.20	1,504
1.70	164	2.70	371	3.70	759	5.40	1,610
1.80	180	2.80	402	3.80	804	5.60	1,717
1.90	197	2.90	436	3.90	850	5.80	1,825
2.00	214	3.00	472	4.00	897	6.00	1,935
2.10	232	3.10	510	4.20	993		

[a] The rating curve on which this table is based has been drawn through one measurement made 1905, and has the form of the 1906 curve.

[b] This table is strictly applicable only for open-channel conditions. The rating curve has been through one measurement made November, 1905, and has the form of the 1906 curve.

[c] This table is strictly applicable only for open-channel conditions. It is based on five disc *measurements* made during 1906. It is fairly well defined between gage heights 1.5 feet and 3.4 *Above gage height* 6.0 feet the rating curve is a tangent, the difference being 55 per tenth.

Estimated monthly discharge of Opequon Creek near Martinsburg, W. Va.

[Drainage area, 275 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
ıy 9–31	253	116	144	0.524	0.448
ne 1–4	140	123	131	.476	.071
tober 8–31	155	50	67.4	.245	.219
›vember	90	50	61.1	.222	.248
›cember	2,826	54	337	1.23	1.42
1906.					
nuary	3,436	153	352	1.28	1.48
bruary	149	107	123	.447	.466
ırch	2,771	104	480	1.75	2.02
›ril	3,310	205	509	1.85	2.06
ıy	200	122	151	.549	.633
ne	1,599	122	338	1.23	1.37
ly 1–15	2,980	138	387	1.41	.786

TUSCARORA CREEK AT MARTINSBURG, W. VA.

Tuscarora Creek rises in Little North Mountain, in the western art of Berkeley County, W. Va., and flows southeastward into)pequon Creek about 2 miles southeast of Martinsburg.

The gaging station was established May 8, 1905, by F. H. Tilling-ast. It is located at the dam formerly used to impound water for ne use of the city of Martinsburg.

The channel is curved for 20 feet above the dam and straight for 00 feet beyond this point. The channel below is a steep race way rom the crest of the dam, paved with riprap. The current is swift. Both banks are low, clean, and not liable to overflow. The bed of he stream above the dam is fairly uniform and shallow, with a mud ›ottom. There is but one channel at all stages. The stream is liable o small fluctuations, owing to the varying demands of factories ıbove the station. The water level at the gage is somewhat unsteady. The velocity of approach is high.

It was intended to determine the discharge by applying the weir ormula to the flow over the crest of the dam.

A vertical staff gage is bolted to the upstream face of the left abut-nent, the zero being set at the level of the floor of the spillway. The gage was read twice each day by B. N. Martin. Bench mark No. 1 s the crest of the dam at the left corner; elevation, 0.04 foot below the gage datum. Bench mark No. 2 is the crest of the dam at the right corner; elevation, 0.04 foot above the gage datum.

A current-meter measurement, made May 9, 1905, at gage height 0.78 foot, gave a discharge of 25.2 second-feet.

Owing to poor conditions and especially to the collection of debris on the crest of the dam, rendering estimates based on the gage heights of little value, this station was abandoned December 31, 1905.

Daily gage height, in feet, of Tuscarora Creek at Martinsburg, W. Va.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.								
1		0.72	0.6	1.55	0.68	0.75	0.85	0.5
2		.64	.7	1.75	.75	.82	.9	.6
3		.62	.72	1.65	.85	.70	.88	1.0
4		.65	.75	1.7	.75	.85	.88	.8
5		.62	.68	1.75	.65	.75	.8	.6
6		.61	.85	1.75	.6	.68	.85	.5
7		.9	.82	1.3	.58	.75	.88	.5
8	0.75	.68	.72	1.4	.7	.78	.6	.5
9	.8	.62	.78	1.3	.55	.68	.58	.5
10	.8	.62	.78	1.25	.6	.65	.55	.5
11	.74	.6	.85	.88	.58	.55	.58	.5
12	.75	.18	1.45	.88	.7	.55	.58	.5
13	.72	.5	2.65	.85	.65	.78	.55	.5
14	.75	.7	3.0	.78	.55	.68	.55	.5
15	.82	.68	2.35	.92	.55	.65	.58	.6
16	.76	.72	1.15	.78	.55	.70	.6	.7
17	.8	.65	.85	.8	.65	.78	.52	.5
18	.78	.75	.82	1.25	.55	.68	.55	.6
19	.75	.78	.78	1.02	.55	.72	.5	.6
20	.72	.72	.78	1.05	.6	.65	.52	.7
21	.72	.78	.68	1.02	.65	.58	.55	.8
22	.74	.8	.7	1.1	.6	.75	.52	2.1
23	.72	.72	1.02	1.08	.55	.75	.58	1.8
24	.74	.28	1.45	1.5	.55	.68	.5	1.3
25	.68	.14	1.25	1.15	.55	.58	.58	1.0
26	.62	.42	1.1	.98	.48	.65	.55	.7
27	.6	.72	1.6	1.35	.48	.68	.62	.6
28	.6	.75	1.5	2.0	.75	.58	.65	.7
29	.62	.72	1.85	.85	.65	.85	.55	.7
30	.59	.68	1.55	.8	.75	.92	.5	.7
31	.78		1.55	.7		.82		

ANTIETAM CREEK NEAR SHARPSBURG, MD.

Antietam Creek drains a rolling, fertile country with uniform declivity and is uninterrupted by natural falls or rapids. It is utilized to a considerable extent to run mills of various kinds.

The gaging station was established June 24, 1897, by A. P. Davis, and was discontinued August 26, 1905. It is located 1 mile east of Sharpsburg, a few hundred feet below the bridge on the toll road from Sharpsburg to Keedysville, Md. There is an old dam, not now in use, just below the bridge.

The channel is straight for 300 feet above and below the station. It has a width at ordinary stages of about 90 feet, and is shallow and unobstructed. There is a good measurable velocity at all stages. The right bank is low and liable to overflow; the left bank is high and rocky; both are fringed with trees. The bed of the stream is composed of gravel, is free from vegetation, and is permanent. There is but one channel at all stages.

Discharge measurements were made from a steel-wire cable, which is supported by the forks of a sycamore tree on each bank and is anchored to timbers set in the ground.

The gage was a vertical rod driven into the gravel of the stream bed and spiked to a tree on the left bank near the cable. It was

read once each day. The bench mark is a copper bolt set in a ledge of rock on the left bank at a point about 125 feet above the cable. Its elevation is 16.34 feet above gage datum.

All estimates previously published have been revised. Estimates for stages below gage height 2.0 feet are probably within 10 per cent of the true discharge for normal conditions of flow; estimates between gage heights 2.0 feet and 4.0 feet are within 5 per cent, and estimates above gage height 4.0 feet are within 10 per cent. Allowance has been made for the discharge of the overflow section. The flow is probably affected to a greater or less extent by ice conditions.

A summary of the records gives the following results: Maximum discharge for twenty-four hours, 6,835 second-feet; minimum discharge for twenty-four hours, 59 second-feet; mean annual discharge for five years, 350 second-feet; mean annual rainfall for seven years, 37.56 inches.

Discharge measurements of Antietam Creek near Sharpsburg, Md.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Second-feet.*		*Feet.*	*Second-feet.*
1897.			1900.		
June 24	2.00	251	September 16	1.77	131
July 2	2.05	240			
September 3	1.60	122	1901.		
October 12[a]	1.70	120	July 30	1.90	185
			December 28	2.20	266
1898.					
January 24	2.70	427	1902.		
August 19	3.50	831	September 1	1.70	126
1899.			1903.		
January 27	2.80	495	March 13	3.06	584
May 20	2.60	418	September 4	2.10	224
September 5	1.80	118			
			1904.		
1900.			July 1	1.79	158
June 28	1.80	139	July 11	1.79	150

[a] Measurement made near mouth of stream.

Daily gage height, in feet, of Antietam Creek near Sharpsburg, Md.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897.							1897.						
1	1.9	1.5	1.7	1.5	1.45	1.7	16	1.8	1.9	1.7	1.65	1.75	2.4
2	2.1	1.7	1.7	1.6	2.7	1.6	17	1.75	1.8	1.6	1.6	1.7	2.2
3	1.85	1.7	1.6	1.4	2.1	1.6	18	1.7	1.7	1.6	1.4	1.6	2.1
4	1.7	1.75	1.6	1.6	1.9	1.7	19	1.75	1.6	1.6	1.5	1.5	2.0
5	1.75	1.6	1.5	1.7	1.6	2.25	20	1.75	1.5	1.5	1.5	1.7	1.6	2.1
6	1.8	1.7	1.7	1.6	1.6	2.45	21	1.85	1.5	1.6	1.7	1.7	2.0
7	1.7	1.7	1.7	1.7	1.7	2.05	22	1.85	1.55	1.6	1.6	1.6	2.0
8	1.7	1.5	1.6	1.6	1.75	2.0	23	1.7	1.6	1.7	1.6	1.5	2.1
9	1.7	1.4	1.65	1.5	1.8	1.8	24	1.7	3.0	1.9	1.65	1.7	2.5
10	1.7	1.7	1.6	1.4	1.6	1.9	25	1.55	2.9	1.8	1.65	1.8	2.2
11	1.55	1.9	1.6	1.5	1.55	1.9	26	1.65	2.0	1.5	1.8	1.8	2.0
12	1.75	1.85	1.5	1.6	1.5	1.9	27	1.75	1.75	1.7	1.7	1.9	2.0
13	1.95	1.6	1.4	1.7	1.6	2.05	28	1.8	1.7	1.6	1.6	2.0	1.9
14	1.8	1.7	1.5	1.5	1.4	2.0	29	1.85	1.55	1.6	1.6	1.9	1.8
15	1.8	2.45	1.6	1.6	1.5	2.35	30	1.8	1.8	1.5	1.6	1.8	1.8
							31	1.7	1.7	.....	1.5	.....	1.9

Daily gage height, in feet, of Antietam Creek near Sharpsburg, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1898.											
1	2.0	2.4	2.1	2.8	2.0	2.4	1.8	2.0	1.9	1.8	2.1
2	2.4	2.6	2.1	2.7	2.0	2.3	1.7	1.9	1.9	1.8	2.1
3	2.1	2.9	2.1	2.6	2.0	2.2	1.8	1.8	1.9	1.7	2.0
4	1.8	2.5	2.1	2.5	2.0	2.2	1.8	1.9	1.9	1.7	2.1
5	1.7	2.4	2.2	2.6	2.0	2.1	1.8	2.5	2.1	1.7	1.9
6	1.5	2.2	2.1	2.5	2.1	2.2	1.8	2.0	2.0	1.6	1.8
7	1.9	2.4	2.1	2.5	2.2	2.2	1.7	1.8	1.9	1.7	1.8
8	1.8	2.2	2.1	2.5	2.4	2.1	1.7	1.8	1.9	1.6	1.7
9	1.7	2.1	2.0	2.4	3.25	2.1	1.8	2.0	1.9	1.6	1.7
10	2.0	2.1	2.0	2.4	2.7	2.1	1.8	3.1	1.8	1.6	1.9
11	2.1	2.3	2.1	2.4	2.5	2.1	1.8	3.05	1.7	1.6	2.5
12	1.9	2.2	2.1	2.3	2.4	2.15	1.8	2.3	1.9	1.8	2.15
13	2.0	2.2	2.0	2.3	2.5	2.2	1.8	2.1	1.8	1.7	2.2
14	1.8	2.2	2.0	2.3	2.3	2.2	1.8	2.0	1.8	1.8	2.2
15	2.9	2.2	2.1	2.35	2.3	2.1	1.8	2.05	1.9	1.7	2.0
16	3.15	2.1	2.0	2.4	2.9	2.1	1.7	2.0	1.8	1.5	2.0
17	2.9	2.0	2.2	2.3	3.0	2.1	1.7	2.0	1.8	1.6	1.9
18	2.5	2.2	2.2	2.3	2.8	2.1	1.8	5.07	1.7	2.75	2.0
19	2.3	2.3	2.2	2.3	2.6	2.0	1.8	3.65	1.9	1.8	2.6
20	2.4	2.1	2.0	2.3	2.4	2.1	1.8	2.95	1.8	2.4	2.5
21	2.4	2.6	2.1	2.2	2.4	2.0	1.8	2.45	1.8	2.2	2.4
22	2.2	2.6	2.5	2.2	3.1	1.9	1.8	2.3	1.8	2.9	2.4
23	2.85	2.4	2.55	2.2	2.5	2.1	1.8	2.1	1.9	2.8	2.3
24	2.8	2.6	2.7	2.2	3.0	2.1	1.8	2.0	1.9	1.9	2.4
25	2.6	2.3	3.25	2.3	2.7	1.9	2.2	1.9	1.8	1.7	2.3
26	2.6	2.3	2.95	2.3	2.9	1.9	1.9	2.0	1.8	2.4	2.3
27	2.6	2.2	2.8	2.2	2.7	1.9	1.9	2.0	1.9	2.3	2.3
28	2.5	2.3	2.7	2.2	2.7	1.8	1.8	1.9	1.8	2.1	2.3
29	2.5	.....	2.75	2.2	2.6	1.8	1.8	2.0	1.9	2.1	2.2
30	2.4	.....	3.1	2.1	2.5	1.8	1.8	2.0	1.8	2.1	2.2
31	2.5	.....	2.9	.....	2.4	.....	1.9	2.0	.....	2.1	.....
1899.											
1	2.8	2.7	4.75	3.4	2.4	2.4	2.1	1.7	1.8	1.8	2.4
2	2.7	2.6	4.2	3.3	2.45	3.75	1.9	1.6	1.8	1.8	2.25
3	2.6	2.6	4.1	3.2	2.9	2.6	2.0	2.55	1.7	1.7	2.0
4	2.7	2.6	3.85	3.2	2.5	2.6	1.85	1.9	2.0	1.6	1.8
5	3.0	2.8	4.8	3.1	2.5	2.4	1.9	1.8	1.8	1.6	1.8
6	3.4	2.8	4.4	3.0	2.5	2.4	1.8	1.7	1.8	1.5	1.9
7	3.55	2.5	4.05	2.9	2.4	2.3	2.0	1.9	1.7	1.5	1.8
8	3.2	2.4	3.9	3.25	2.55	2.3	1.9	1.7	1.7	1.5	1.5
9	3.0	2.6	3.6	3.1	2.7	2.45	1.9	1.7	1.85	1.7	1.6
10	3.0	2.8	3.5	3.0	2.55	2.7	2.0	1.8	1.6	1.6	1.7
11	2.9	2.6	3.5	2.9	2.5	2.65	1.9	1.8	2.3	1.5	1.6
12	2.8	2.8	3.4	2.8	2.5	2.4	1.8	2.35	2.1	1.5	1.7
13	2.9	2.8	3.3	2.8	2.5	2.4	2.15	1.9	1.85	1.5	1.7
14	3.0	2.8	3.2	2.8	2.4	2.35	2.0	2.0	1.8	1.5	1.6
15	3.0	2.9	3.2	2.8	2.3	2.3	1.9	1.9	1.7	1.4	1.6
16	3.0	2.9	3.5	2.8	2.4	2.3	1.85	1.8	1.6	1.8	1.6
17	3.0	2.8	3.2	2.7	2.2	2.3	1.95	1.9	1.6	1.7	1.8
18	3.0	2.9	3.2	2.7	3.15	2.2	1.8	1.8	1.7	1.6	1.7
19	2.9	2.9	3.7	2.7	2.8	2.25	1.85	1.8	2.0	1.6	1.7
20	2.8	2.8	3.75	2.6	2.6	2.2	1.8	1.6	1.9	1.6	1.7
21	2.8	3.2	3.4	2.6	2.5	2.2	1.8	1.8	1.9	1.6	1.7
22	2.8	4.3	3.4	2.6	2.5	2.1	1.8	1.7	1.8	1.6	1.8
23	2.8	4.1	3.5	2.5	2.5	2.0	2.05	1.8	1.8	1.7	1.8
24	2.8	3.7	3.4	2.4	2.4	2.1	1.9	1.7	1.7	1.6	1.7
25	3.25	3.5	3.3	2.5	2.3	2.05	1.7	1.65	1.9	1.6	1.6
26	2.9	4.5	3.2	2.45	2.3	2.2	1.75	1.7	1.9	1.5	1.6
27	2.9	5.4	3.0	2.5	2.3	2.1	1.7	3.45	1.8	1.5	1.7
28	2.8	5.15	3.5	2.5	2.3	2.15	1.6	2.8	1.8	1.5	1.6
29	2.8	.....	3.9	2.5	2.2	2.1	1.6	2.3	1.9	1.5	1.7
30	2.7	.....	3.7	2.4	2.45	2.2	1.6	2.0	1.9	1.6	1.7
31	2.7	.....	3.5	.....	2.4	.....	1.8	1.9	.....	1.6	.....

Daily gage height, in feet, of Antietam Creek near Sharpsburg, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1900.												
	1.5	1.6	3.8	2.5	2.1	2.0	1.7	1.4	1.6	1.4	1.7	1.55
	1.5	1.7	3.6	2.5	2.1	1.9	1.7	1.4	1.6	1.5	1.5	1.55
	1.5	1.6	3.0	2.4	2.0	1.9	1.6	1.5	1.4	1.4	1.5	1.5
	1.6	1.5	2.8	2.3	2.1	2.0	1.5	1.5	1.6	1.4	1.5	2.3
	1.6	1.5	2.7	2.3	2.0	1.9	1.7	1.4	1.7	1.5	1.5	2.4
	1.7	1.6	2.7	2.3	1.9	1.9	1.7	1.4	1.6	1.4	1.4	2.0
	1.7	1.5	2.75	2.4	2.1	1.9	1.6	1.4	1.5	1.4	1.5	1.6
	1.8	2.0	2.6	2.3	2.0	1.9	1.6	1.4	1.5	1.3	1.6	1.7
	1.9	2.2	2.5	2.3	2.0	1.9	1.7	1.45	1.4	1.5	1.6	1.7
	1.8	2.0	2.5	2.2	1.9	1.7	1.6	1.5	1.4	1.6	1.6	1.6
	1.8	1.9	2.5	2.2	1.8	2.0	1.5	1.4	1.4	1.6	1.5	1.6
	1.8	2.0	2.5	2.3	1.9	1.9	1.55	1.5	1.4	1.5	1.4	1.5
	1.7	2.7	2.4	2.3	1.8	1.8	1.5	1.5	1.5	1.5	1.7	1.5
	1.7	2.7	2.4	2.3	1.8	1.7	1.55	1.4	1.6	2.05	1.5	1.5
	1.8	2.4	2.4	2.2	2.0	1.7	1.6	1.7	1.6	1.9	1.7	1.4
	1.7	2.4	2.4	2.3	1.9	1.85	1.45	1.6	1.8	1.7	1.5	1.3
	1.7	2.2	2.3	2.2	2.0	2.1	1.5	1.6	.....	1.6	1.5	1.5
	1.7	2.1	2.25	2.3	2.0	2.2	1.5	1.6	1.4	1.4	1.4	1.4
	1.8	2.2	2.4	2.35	2.4	2.55	1.5	1.6	1.5	1.6	1.5	1.5
	2.1	2.2	2.9	2.3	3.1	2.1	1.6	1.7	1.5	1.6	1.5	1.5
	2.5	2.3	3.1	2.7	2.4	2.0	1.5	1.8	1.5	1.4	1.6	1.5
	2.0	4.15	2.8	2.3	2.2	1.9	1.4	1.8	1.4	1.5	1.5	1.5
	1.9	3.75	2.7	2.4	2.1	1.8	1.9	1.7	1.4	1.5	1.5	1.5
	1.8	3.05	2.7	2.3	2.1	1.7	1.85	1.7	1.3	1.8	1.5	1.4
	1.7	3.8	2.6	2.2	2.1	1.8	1.65	1.8	1.4	1.7	1.5	1.3
	2.3	3.3	2.5	2.2	2.0	1.8	2.0	1.7	1.4	1.5	2.5	1.6
	2.2	3.0	2.6	2.1	1.9	1.9	1.9	1.7	1.4	1.5	2.1	1.5
	2.0	3.0	2.5	2.1	1.9	1.8	1.8	2.0	1.4	1.4	1.8	1.5
	1.8	.....	2.5	2.1	2.0	1.8	1.55	1.9	1.5	1.3	1.7	1.5
	1.6	.....	2.6	2.0	1.9	1.7	1.4	1.8	1.6	1.4	1.6	1.4
	1.6	.....	2.6	.....	2.1	.....	1.4	1.7	.....	1.6	.....	1.5
1901.												
	1.5	1.5	1.5	2.8	2.5	2.8	2.2	1.9	2.5	2.0	1.6	.....
	1.5	1.4	1.5	2.7	2.5	2.8	2.1	1.8	2.3	1.9	1.6	.....
	1.4	1.4	1.4	3.3	2.4	2.6	2.1	1.7	2.1	2.2	1.4	.....
	1.4	1.4	1.5	5.25	2.4	2.5	2.0	1.7	2.0	2.0	1.5	.....
	1.4	1.5	1.6	3.65	2.4	2.5	2.1	1.8	2.0	1.8	1.5	.....
	1.4	1.6	1.5	3.4	2.3	2.5	2.1	2.1	1.9	1.8	1.5	.....
	1.4	1.6	1.8	3.3	2.2	2.8	2.1	2.6	1.8	1.8	1.6	.....
	1.4	1.5	1.7	3.2	2.3	2.7	2.1	2.4	1.7	1.7	1.6	.....
	1.4	1.5	1.6	3.1	2.3	2.6	2.0	2.2	1.6	1.7	1.6	.....
	1.5	1.4	1.6	2.85	2.2	2.4	2.0	2.0	1.6	1.6	1.6	.....
	1.5	1.4	5.35	2.7	2.1	2.3	2.1	1.9	1.6	1.6	1.6	.....
	1.7	1.4	3.35	2.6	2.3	2.3	2.2	1.8	1.7	1.6	1.6	.....
	1.6	1.3	2.45	2.5	2.2	2.2	2.1	1.8	1.7	1.6	1.5	.....
	1.6	1.5	2.2	2.7	2.2	2.2	2.1	1.7	1.6	1.7	1.5	.....
	1.5	1.4	2.3	4.3	2.2	2.4	2.1	3.9	2.6	1.7	1.5	.....
	1.5	1.6	2.2	3.45	2.2	2.8	2.2	2.2	2.0	1.6	1.4	.....
	1.6	1.4	2.2	2.9	2.2	2.6	2.5	2.1	2.1	1.6	.....	.....
	1.5	1.5	2.1	2.7	2.2	2.5	2.2	2.0	2.0	1.5	.....	.....
	1.4	1.6	2.1	2.6	2.2	2.4	2.1	1.9	1.8	1.5	.....	.....
	1.4	1.6	2.0	2.95	2.15	2.3	2.0	1.8	1.7	1.6	.....	.....
	1.5	1.7	2.45	3.6	2.1	2.3	2.5	1.9	1.7	1.6	.....	.....
	1.5	1.7	2.4	3.6	4.8	2.3	2.2	1.8	1.7	1.5	.....	.....
	1.6	1.8	2.2	3.2	6.3	2.3	2.1	1.9	1.7	1.5	.....	.....
	1.6	1.6	2.2	3.0	3.7	2.3	2.1	2.0	1.7	1.5	.....	.....
	1.6	1.3	2.1	2.9	3.85	2.2	2.5	2.0	1.6	1.5	.....	.....
	1.6	1.4	2.2	2.8	3.4	2.2	2.1	2.0	1.6	1.8	.....	.....
	1.4	1.5	2.25	2.9	3.4	2.3	2.1	1.9	1.7	1.7	.....	.....
	1.4	1.5	2.2	2.8	3.1	2.3	2.0	1.7	1.7	1.7	.....	2.2
	1.5	.....	2.2	2.7	3.0	2.35	1.9	1.7	1.6	1.6	.....	4.7
	1.5	.....	2.1	2.6	3.5	2.2	1.9	1.7	2.15	1.7	.....	4.5
	1.5	.....	2.2	.....	3.0	.....	1.8	2.05	.....	1.7	.....	3.3

Daily gage height, in feet, of Antietam Creek near Sharpsburg, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	D
1902.												
1	2.9	2.4	7.0	2.9	2.6	2.1	2.2	2.6	1.7	1.7	1.6	
2	2.7	2.4	5.05	2.9	2.5	2.2	2.1	2.4	1.6	1.8	1.7	
3	2.7	2.6	4.6	2.8	2.5	2.2	2.1	1.8	1.6	1.6	1.7	
4	2.5	2.5	3.9	2.8	2.5	2.2	2.0	1.8	1.7	1.6	1.6	
5	2.4	2.4	4.0	2.8	2.5	2.1	2.0	1.9	1.6	2.3	1.6	
6	2.4	2.3	3.6	2.7	2.4	2.1	1.9	1.9	1.5	2.1	1.7	
7	2.3	2.2	3.5	2.9	2.4	2.1	2.3	1.9	1.5	1.9	1.7	
8	2.3	2.1	3.5	3.9	2.4	2.0	2.7	1.7	1.4	1.7	1.7	
9	2.3	2.1	3.7	6.45	2.3	2.0	2.7	1.7	1.6	1.7	1.7	
10	2.3	2.3	4.2	4.45	2.3	2.0	3.5	1.6	1.6	1.6	1.7	
11	2.3	2.4	4.4	3.9	2.4	2.0	2.0	1.8	1.7	1.8	1.6	
12	2.2	2.2	4.4	3.6	2.3	2.1	2.0	1.8	1.6	1.8	1.6	
13	2.2	2.3	4.8	3.5	2.3	2.2	1.8	1.7	1.7	2.1	1.6	
14	2.2	2.2	4.7	3.3	2.3	2.2	1.8	1.6	1.5	1.9	1.5	
15	2.1	2.2	3.9	3.2	2.3	2.2	1.8	1.6	1.4	1.8	1.5	
16	2.1	2.0	3.7	3.1	2.2	2.3	1.8	1.6	1.6	1.7	1.6	
17	2.1	2.2	5.1	3.1	2.2	2.4	1.7	1.4	1.6	1.7	1.7	
18	2.1	2.1	4.2	3.0	2.2	2.4	1.7	1.4	1.6	1.7	1.7	
19	2.1	1.9	3.7	2.9	2.9	2.2	2.4	1.5	1.6	1.6	1.6	
20	2.1	2.0	3.5	2.9	2.4	2.3	2.7	1.5	1.5	1.8	1.6	
21	3.8	3.15	3.6	2.8	2.3	2.3	1.8	2.0	1.5	1.7	1.6	
22	4.25	4.7	3.4	2.8	2.3	2.0	1.8	2.0	1.4	1.7	1.5	
23	2.7	3.6	3.4	2.8	2.2	2.0	1.7	1.9	1.5	1.8	1.5	
24	2.4	3.5	3.4	2.7	2.2	2.0	1.7	1.7	1.7	1.7	1.5	
25	2.4	6.2	3.1	2.7	2.4	1.9	1.9	1.5	1.7	1.7	1.6	
26	2.3	10.5[a]	3.0	2.6	2.6	2.2	1.8	1.5	1 8	1.7	1.8	
27	4.25	5.15	3.0	2.6	2.2	2.2	1.8	1.5	2.3	1 7	2.2	
28	3.2	7.45	2.9	2.6	2.3	2.2	1.7	1.6	1.6	1.7	2.1	
29	2.7	.....	3.4	2.6	2.2	2.2	1.7	1.5	1.6	2.1	1.8	
30	2.6	.....	3.1	2.7	2.2	2.4	1.9	1.5	1.5	1.8	2.3	
31	2.4	.....	3.0	.....	2.2	.....	2.55	1.4	.....	1.6	.....	
1903.[b]												
1	3.7	3.5	4.3	3.2	2.9	2.5	3.9	2.5	2.3	2.0	1.85	
2	3.9	3.2	3.8	3.1	2.9	2.4	3.0	2.5	2.2	1.95	1.9	
3	4.8	3.4	3.6	3.1	2.9	2.3	2.8	2.4	2.2	1.95	1.9	
4	4.5	4.1	3.9	3.2	2.8	2.3	3.0	2.4	2.1	2.0	1.9	
5	4.3	3.8	4.1	3.0	2.9	2.3	3.0	2.6	2.1	1.9	1.8	
6	4.3	3.5	3.8	2.9	2.8	2.35	3.8	2.6	2.05	1.9	1.8	
7	4.1	3.2	4.0	3.0	2.7	2.4	2.9	2.7	2.0	1.85	1.8	
8	3.8	3.2	3.8	3.2	2.7	2.45	2.8	2.5	2.1	3.0	1.85	
9	3.6	3.4	3.6	3.3	2.7	2.6	2.7	2.6	2.3	2.5	1.85	
10	2.8	3.3	3.5	3.1	2.6	2.4	2.7	2.6	2.2	2.2	1.85	
11	2.8	4.5	3.3	3.1	2.6	2.35	3.3	2.5	2.1	2.1	1.8	
12	2.7	4.7	3.2	3.1	2.5	2.5	c7.9	2.5	2.1	2.1	1.9	
13	2.7	4.5	3.1	3.1	2.5	2.5	6.1	2.3	2.1	2.1	1.9	
14	2.6	4.0	3.0	4.5	2.4	2.45	3.7	2.3	2.2	2.0	1.9	
15	2.6	3.8	3.0	5.7	2.4	2.5	3.3	2.2	2.2	2.0	1.85	
16	2.7	3.7	2.9	6.7	2.4	2.4	3.0	3.6	2.1	2.1	1.85	
17	2.6	3.5	2.9	5.45	2.5	2.3	3.0	3.2	3.0	2.15	1.95	
18	2.6	3.2	2.8	4.6	2.4	2.4	3.2	2.4	2.4	2.05	1.9	
19	2.7	3.0	2.8	4.3	2.4	2.3	3.2	2.4	2.2	2.0	1.9	
20	2.9	2.8	2.7	4.0	2.4	2.5	3.0	2.3	2.2	2.1	1.9	
21	3.5	2.6	2.9	3.8	2.4	2.4	3.0	2.2	2.1	2.1	1.9	
22	3.9	2.5	3.0	3.6	2.4	2.3	3.0	2.2	2.0	2.1	1.95	
23	3.7	2.5	3.1	3.5	2.4	2.4	2.7	2.2	1.9	2.1	1.95	
24	3.5	2.3	3.5	3.4	2.6	2.3	2.7	2.2	1.9	2.1	1.95	
25	3.5	2.6	3.3	3.4	2.5	2.35	2.6	2.2	1.9	2.0	2.0	
26	3.6	3.0	3.2	3.3	2.5	2.3	2.6	2.3	2.0	2.0	1.8	
27	4.2	4.45	3.1	3.2	2.4	2.3	2.5	2.1	2.0	2.0	1.8	
28	4.4	5.75	2.9	3.1	2.4	2.3	2.5	2.0	2.0	2.0	1.9	
29	4.2	.....	2.8	3.0	2.3	3.6	2.7	2.7	1.9	2.0	1.9	
30	3.9	.....	4.2	3.0	3.3	3.1	2.8	2.5	1.9	1.9	1.9	
31	3.5	.....	4.0	.....	2.6	.....	2.7	2.4	.....	1.9	.....	

[a] Gage height estimated February 26, 1902.
[b] Ice conditions during part of December, 1903.
[c] Highest record, 10.2 feet, 6 p. m., July 12, 1903.

Daily gage height, in feet, of Antietam Creek near Sharpsburg, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.[a]												
1	1.9							1.6	1.5	1.45	1.5	1.45
2	1.9							1.6	1.5	1.45	1.5	1.45
3	1.75							1.8	1.5	1.4	1.45	1.45
4	2.1							1.65	1.6	1.55	1.5	1.45
5	1.9							1.6	1.55	1.5	1.5	1.4
6	1.9							1.6	1.5	1.45	1.45	1.5
7	1.8							1.6	1.45	1.5	1.4	1.45
8	1.8							1.5	1.55	1.45	1.5	1.45
9	1.8							1.5	1.45	1.45	1.5	1.45
10	1.85							1.5	1.85	1.5	1.5	1.5
11	1.85							3.0	1.6	1.5	1.5	1.55
12	1.9						[b]2.2	1.8	1.55	1.5	1.5	1.4
13	1.85						2.2	1.65	1.5	1.75	1.6	1.6
14	1.85						1.9	1.55	1.65	1.6	1.5	1.5
15	1.7						1.75	1.6	1.65	1.5	1.65	1.45
16	1.7						1.7	1.6	1.8	1.45	1.5	1.55
17	1.7						1.7	1.6	1.6	1.4	1.5	1.55
18	1.8						1.7	1.6	1.5	1.5	1.4	1.55
19	1.8						1.7	1.65	1.4	1.5	1.4	1.55
20	1.8						1.6	1.6	1.65	1.5	1.5	1.6
21	1.85						1.65	1.6	1.6	1.65	1.5	1.65
22	3.9						1.6	1.6	1.6	1.95	1.55	1.65
23	[b]6.0						1.7	1.85	1.55	1.65	1.55	1.55
24							1.75	1.75	1.5	1.6	1.5	1.6
25							1.85	1.6	1.45	1.5	1.55	1.65
26							1.7	1.6	1.5	1.55	1.5	1.75
27							1.6	1.55	1.55	1.5	1.45	1.7
28							1.6	1.45	1.5	1.5	1.35	1.8
29							1.85	1.5	1.5	1.55	1.45	2.15
30							1.7	1.5	1.45	1.45	1.5	2.05
31							1.6	1.5		1.5		1.75
1905.[c]												
1	1.65	1.85	1.75	2.75	2.1	1.85	1.8	2.25				
2	1.6	1.9	1.7	2.6	2.1	1.9	1.8	2.05				
3	1.7	1.9	1.7	2.6	2.05	1.8	1.85	2.0				
4	1.75	1.8	1.7	2.6	2.05	1.75	1.8	2.0				
5	1.9	1.75	1.95	2.7	2.0	1.7	2.95	2.0				
6	1.75	2.0	2.0	2.8	2.0	1.75	2.1	2.0				
7	3.5	1.9	2.1	2.65	2.0	2.15	2.0	2.0				
8	2.7	2.0	2.15	2.55	2.05	2.1	1.95	2.2				
9	2.25	1.85	2.8	2.5	2.0	1.95	1.85	2.35				
10	2.1	1.85	3.4	2.5	2.0	1.8	1.8	2.3				
11	2.1	1.9	3.05	2.55	1.95	1.8	1.75	2.0				
12	2.05	1.8	2.95	2.55	2.0	2.1	1.85	2.0				
13	2.45	1.9	2.8	2.45	1.95	2.2	1.8	1.9				
14	2.2	1.9	2.8	2.5	1.95	2.0	1.85	1.9				
15	2.05	1.75	2.7	2.45	2.05	1.9	3.25	2.0				
16	2.45	1.8	2.6	2.4	2.0	1.8	2.15	2.3				
17	2.55	1.8	2.7	2.4	2.0	1.8	2.05	2.3				
18	2.1	1.85	2.95	2.3	2.25	1.75	2.0	2.1				
19	1.95	1.8	3.1	2.3	2.05	1.7	2.45	2.1				
20	1.9	1.85	3.6	2.3	2.05	1.8	2.4	2.1				
21	1.9	1.8	3.6	2.3	1.95	2.05	1.9	2.1				
22	1.9	1.7	3.4	2.3	1.9	2.0	1.8	2.3				
23	1.85	1.7	3.2	2.2	1.85	2.0	2.25	2.2				
24	1.75	1.7	3.05	2.2	1.8	2.6	5.0	2.1				
25	1.8	1.7	3.95	2.2	1.8	2.2	3.65	6.05				
26	1.8	1.75	3.8	2.1	1.8	1.9	2.25	[d]				
27	2.05	1.95	3.35	2.1	1.85	2.0	2.0					
28	2.0	1.85	3.1	2.1	1.8	1.95	2.0					
29	2.0		3.0	2.1	1.85	1.95	2.0					
30	1.9		2.9	2.1	1.9	1.85	2.65					
31	1.9		2.8		1.9		2.45					

[a] Ice conditions during January, 1904.
[b] Ice carried gage away January 23, 1904; reestablished July 12, 1904.
[c] Ice conditions during part of February, 1905.
[d] Gage washed out August 26, 1905.

Rating table for Antietam Creek near Sharpsburg, Md., from June 24, 1897, to August 25, 1905.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.30	59	2.60	399	3.90	1,035	6.40	2,705
1.40	74	2.70	437	4.00	1,095	6.60	2,955
1.50	91	2.80	476	4.20	1,215	6.80	3,125
1.60	110	2.90	517	4.40	1,345	7.00	3,295
1.70	131	3.00	560	4.60	1,475	7.50	3,740
1.80	153	3.10	605	4.80	1,610	8.00	4,205
1.90	177	3.20	652	5.00	1,750	8.50	4,690
2.00	203	3.30	701	5.20	1,890	9.00	5,195
2.10	231	3.40	752	5.40	2,030	9.50	5,720
2.20	261	3.50	805	5.60	2,180	10.00	6,270
2.30	293	3.60	860	5.80	2,330	10.50	6,835
2.40	327	3.70	915	6.00	2,480		
2.50	362	3.80	975	6.20	2,635		

[a] This table is strictly applicable only for open-channel conditions. It is based on discharge measurements made during 1897–1904. It is well defined between gage heights 1.7 feet and 3.5 feet. Estimates above 3.5 feet and below 1.7 feet are based on the extension of the area and velocity curves. Overflow at this section begins at about gage height 6.0 feet. It was assumed to amount to 300 second-feet at gage height 10.0 feet, or a mean velocity in the overflow portion of about one-half the velocity in the main channel.

Estimated monthly discharge of Antietam Creek near Sharpsburg, Md.

[Drainage area, 295 square miles.]

Month.	Discharge in second-feet.			Run-off.		Precipitation.		
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1897.								
July	231	100	146	0.495	0.571			
August	560	74	161	.546	.630			
September	177	74	114	.386	.431			
October	153	74	109	.369	.425			
November	437	74	140	.475	.530			
December	362	110	210	.712	.821			
1898.								
January	628	91	303	1.03	1.19			
February	517	203	302	1.02	1.06			
March	676	203	312	1.06	1.22			
April	476	231	316	1.07	1.19			
May	676	203	375	1.27	1.46			
June	327	153	226	.766	.855			
July	261	131	159	.539	.621			
August	1,799	153	322	1.09	1.26			
September	231	131	167	.566	6.32			
October	456	91	200	.678	.782			
November	399	131	249	.844	.942			
December	4,015	203	598	2.03	2.34			
The year	4,015	91	294	.997	13.55			
1899.								
January	832	399	529	1.79	2.06	103	2.00	0.06
February	2,030	327	682	2.31	2.40	56	4.30	1.90
March	1,610	560	897	3.04	3.50	88	4.00	.50
April	752	327	483	1.64	1.83	193	.95	.88
May	517	261	358	1.21	1.40	28	5.08	3.68
June	945	203	317	1.07	1.19	28	4.19	3.00
July	246	110	169	.572	.660	60	1.10	.44
August	778	110	200	.678	.782	20	3.85	3.07
September	293	110	160	.542	.605	13	4.68	4.07
October	153	74	109	.369	.425	26	1.63	1.20
November	327	91	144	.488	.544	22	2.46	1.92
December	418	91	133	.451	.520	23	2.26	1.74
The year	2,030	74	349	1.18	15.92	44	36.50	20.58

ated monthly discharge of Antietam Creek near Sharpsburg, Md.—Continued.

th.	Discharge in second-feet.			Run-off.		Per cent of precipitation.	Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.		In inches.	Loss in inches.
0.								
.....	362	91	158	.536	.618	26	2.34	1.72
.....	1,185	91	372	1.26	1.31	34	3.82	2.51
.....	975	277	432	1.46	1.68	62	2.71	1.03
.....	362	203	291	.986	1.10	80	1.38	.28
.....	605	153	222	.753	.868	34	2.52	1.65
.....	380	131	181	.614	.685	15	4.52	3.84
.....	203	74	115	.390	.450	10	4.34	3.89
.....	203	74	112	.380	.438	15	3.00	2.56
[a].....	153	74	91.7	.311	.347	16	2.25	1.90
.....	217	59	99.1	.336	.387	28	1.37	.98
.....	362	74	114	.386	.431	14	3.07	2.64
.....	327	59	110	.373	.430	27	1.59	1.16
year.....	1,185	59	192	.649	8.75	27	32.91	24.16
1.								
.....	131	74	90.5	.307	.354	16	2.16	1.81
.....	153	59	92.4	.313	.326	52	.63	.30
.....	1,995	74	285	.966	1.11	28	3.92	2.81
.....	1,925	362	632	2.14	2.39	42	5.73	3.34
.....	2,715	231	523	1.77	2.04	36	5.71	3.67
.....	476	261	341	1.16	1.29	29	4.43	3.14
.....	362	153	238	.807	.930	25	3.77	2.84
.....	1,035	131	218	.739	.852	20	4.33	3.48
.....	399	110	171	.580	.647	26	2.51	1.86
.....	261	91	130	.441	.508	57	.89	.38
1-16.....	110	74	98.4	.334	.199	.....	[b] 2.36	.....
28-31.....	1,540	261	978	3.32	.494	.....	[b] 5.83	.....
year.....	.....	.....	.....	.....	.....	.....	42.27	.....
2.								
.....	1,248	231	410	1.39	1.60	48	3.30	1.70
.....	6,835	177	871	2.95	3.07	69	4.44	1.37
.....	3,295	517	1,068	3.62	4.17	105	3.98	−.19
.....	2,835	399	662	2.24	2.50	98	2.54	.04
.....	517	261	313	1.06	1.22	97	1.26	.04
.....	327	177	249	.844	.942	22	4.28	3.34
.....	805	131	232	.786	.906	29	3.09	2.18
.....	399	74	141	.478	5.51	60	.91	.36
.....	293	74	113	.383	.427	26	1.64	1.21
.....	293	110	150	.508	.586	16	3.73	3.14
.....	293	91	131	.444	.495	20	2.48	1.99
.....	1,155	153	570	1.93	2.22	56	3.98	1.76
year.....	6,835	74	409	1.39	18.69	52	35.63	16.94
3.								
.....	1,610	399	843	2.86	3.30	84	3.95	0.65
.....	2,292	293	849	2.88	3.00	109	2.74	−.26
.....	1,280	437	750	2.54	2.93	91	3.23	.30
.....	3,040	517	926	3.14	3.50	94	3.73	.23
.....	701	293	398	1.35	1.56	36	4.28	2.72
.....	860	293	350	1.19	1.33	23	5.86	4.53
.....	4,110	362	738	2.50	2.88	40	7.20	4.32
.....	860	203	354	1.20	1.38	27	5.10	3.72
.....	560	177	242	.820	.915	57	1.60	.68
.....	560	165	226	.766	.883	27	3.21	2.33
.....	203	153	172	.583	.650	47	1.38	.73
[c].....	399	153	195	.661	.762	69	1.11	.35
year.....	4,110	153	504	1.71	23.09	53	43.39	20.30

[a] Discharge interpolated September 17, 1900.
[b] Precipitation for complete month, November and December, 1901.
[c] Ice conditions during part of December, 1903; no correction made in estimates.

Estimated monthly discharge of Antietam Creek near Sharpsburg, Md.—Continued.

Month.	Discharge in second-feet.			Run-off.		Per cent of precipitation.	Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.		In inches.	Loss in inches.
1904.								
January 1-23[a]	2,480	131	300	1.02	.872		[b] 2.42	
February							1.08	
March							1.98	
April							1.95	
May							2.73	
June							5.54	
July 12-31	261	110	145	.492	.366		[b] 4.05	
August	560	82	128	.427	.492	19	2.54	2.05
September	165	74	101	.342	.382	13	2.86	2.48
October	190	74	96.7	.328	.378	15	2.53	2.15
November	120	66	92.8	.315	.351	41	.85	.50
December	246	74	110	.373	.430	17	2.46	2.03
The year							30.99	
1905.								
January	805	110	229	.776	.895	22	4.00	3.10
February [c]	203	131	161	.546	.569	31	1.86	1.29
March	1,005	131	508	1.72	1.98	79	2.50	.52
April	476	231	332	1.13	1.26	68	1.84	.58
May	231	153	190	.664	.766	33	2.31	1.54
June	399	131	190	.644	.718	12	5.84	5.12
July	1,750	142	311	1.06	1.22	18	6.84	5.62
August 1-25	2,518	177	326	1.11	1.03		[d] 4.84	
September							2.11	
October							3.71	
November							1.92	
December							3.48	
The year							41.25	

[a] Ice conditions during January, 1904; no correction made in estimates.
[b] Precipitation for complete month, January and July, 1904.
[c] Ice conditions during part of February, 1905; no correction made in estimates.
[d] Precipitation for complete month, August, 1905.

MISCELLANEOUS DISCHARGE MEASUREMENTS IN POTOMAC RIVER BASIN BETWEEN MOUTH OF SOUTH BRANCH AND SHENANDOAH RIVER.

The following miscellaneous discharge measurements have been made in the drainage basin of Potomac River between the mouth of South Branch and Shenandoah River:

Miscellaneous discharge measurements in Potomac River basin between mouth of South Branch and Shenandoah Rivers.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Square feet.*	*Ft. per second.*	*Sec.-ft.*
1897.						
September 25	Town Creek	200 yards above Chesapeake and Ohio Canal and 3 miles below junction of North and South branches of Potomac River.	22	11	1.00	11
September 29	Little Cacapon River	Near Little Cacapon, W. Va.	4	1.8	.89	1.6
September 26	Purslane Run	Near Pawpaw, W. Va.				.5
Do	Fifteenmile Creek	Near Little Orleans, Md.				.5
Do	Sideling Hill Creek	Above slackwater, near Lineburg, W. Va.	9	2.1	.67	1.4
September 29	Great Cacapon River	One-half mile above mouth, near Great Cacapon, W. Va.	64	123	.66	[a] 81
October 11	Sir Johns Run	Near Sir Johns Run, W. Va.	2.5	.55	1.63	9
Do	Tonoloway Creek	Near Hancock, Md.	8	3.2	1.68	5.4
Do	Potomac River	At Hancock, Md.	180	364	.56	202

[a] Residents state river very low.

Miscellaneous discharge measurements in Potomac River basin between mouth of South Branch and Shenandoah Rivers—Continued.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Square feet.*	*Ft. per second.*	*Sec.-ft.*
1897.						
September 30..	Warm Spring Run...	Below Baltimore and Ohio R. R., near Hancock, Md.	6	2.1	1.28	2.7
October 1.....	Great Tonoloway Creek.	Short distance above Chesapeake and Ohio Canal aqueduct, near Hancock, Md.	9	4	1.40	5.6
Do.....	Sleepy Creek.....	One-fourth mile above Baltimore and Ohio R. R. bridge, near Munson, W. Va.	8	3	.77	2.3
Do.....	Licking Creek.....	Short distance above Chesapeake and Ohio Canal aqueduct, near Ernstville, Md.	33	36	.61	22
October 7.....	Back Creek.....	Near Baltimore and Ohio R. R. bridge, above North Mountain, W. Va.	29	11	.59	6.5
October 8.....	.....do.....	Near mouth, near North Mountain, W. Va.	.....	.....	.....	50
October 7.....	Big Spring Run.....	At Charles Mills, near Big Spring, Md.	4	7.2	.53	3.8
Do.....	Little Conococheague Creek.	At Charles Mills, near Four Locks, Md.	2.5	1.2	2.08	2.5
October 2.....	Conococheague Creek.	500 feet below northeast turnpike bridge, near Williamsport, Md.	125	124	1.60	198
October 8.....	Opequon Creek.....	Near mouth, near Bedington W. Va.	58	65	.77	50
October 9.....	Marsh Run (tributary to Antietam Creek).	Street crossing, below south end drain, Hagerstown, Md.	4	3.1	1.16	3.6
1898.						
October 2.....	Antietam Creek.....	At Stonebreaker's paper mill, near Hagerstown, Md.	68	68	1.03	[a] 70
1894.						
July 2.....	Potomac River.....	At Harpers Ferry, W. Va....	.....	.....	.....	[b] 1,223
1897.						
October 13.....	.....do.....	.....do.....	.....	.....	.....	[c] 377

[a] Gage height on Antietam Creek at Sharpsburg, Md., 1.8 feet.
[b] Gage height on Potomac River at Harpers Ferry, W. Va., 2.52 feet.
[c] 77 second-feet in river, and 300 second-feet in Pulp Company's canal.

SHENANDOAH RIVER BASIN.

SOUTH FORK OF SHENANDOAH RIVER BASIN.

SOUTH RIVER BASIN.

SOUTH RIVER AT BASIC CITY, VA.

South River rises near Greenville, in the southern part of Augusta County, Va., and flows eastward and northward to Port Republic, Rockingham County, where it unites with North River to form South Fork of the Shenandoah. Its drainage area is 245 square miles. It is fed by numerous springs and is utilized to a considerable extent by small mills.

The gaging station was established June 29, 1905, by N. C. Grover, in connection with the investigation of stream pollution in the Shenandoah Valley. It was discontinued July 16, 1906. It is located at the highway bridge one-half mile below the Chesapeake and Ohio Railway bridge at Basic City, Va.

The channel is straight for 300 feet above and 500 feet below the station. The current is sluggish at ordinary stages. Both banks are subject to overflow, the right bank only during very high water. The bed of the stream is composed of rocks and mud and is liable to change after floods. The approximate depth of water is 3 to 4 feet at medium stage. Gage-height observations and measurements are affected by flour mills above the station, which cause rapid fluctuations in the gage height at times.

Discharge measurements were made from the upstream side of the single span bridge to which the gage is fastened. The initial point for soundings is the face of the right abutment.

A standard chain gage is fastened to the upstream hand rail of the bridge. The length of the chain from the end of the weight to the outer edge of the ring is 20.84 feet. The gage was read once each day by F. J. Bates. Bench mark No. 1 is the upstream corner of the lowest step of the wing wall of the bridge at the right bank, nearest the river. It is marked with red paint. Its elevation is 13.97 feet above the datum of the gage.

Estimates at this station above gage height 2.4 feet are considered to be within 5 per cent of the true discharge for normal conditions of flow. Below 2.4 feet the probable error is from 5 to 20 per cent. The flow during the winter of 1905–6 was probably unaffected by ice conditions.

Discharge measurements of South River at Basic City, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1805.	*Feet.*	*Second-feet.*	1905.	*Feet.*	*Second-feet.*
August 5[a]		72	December 29	4.05	454
1905.			1906.		
June 11	2.59	64	April 11	3.25	221
June 29	2.62	90	June 14	2.69	86
September 16	2.52	63			

[a] At rapids, 200 feet above iron bridge.

Discharge measurements of South River at Port Republic, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1895.	*Feet.*	*Second-feet.*	1897.	*Feet.*	*Second-feet.*
st 6	1.62	114	April 19	1.88	202
st 29	1.34	87	June 1	1.87	182
1896.			July 24	1.40	132
5	1.40	113	November 7	1.80	173
30	1.63	139	1899.		
1897.			March 11	3.70	1,582
h 23	2.30	426			

Daily gage height, in feet, of South River at Port Republic, Va.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1895.						1895.					
		1.34	1.2	1.2	1.3	16	1.05	1.3	1.2	1.3	1.3
		1.34	1.2	1.2	1.4	17	1.05	1.3	1.2	1.3	1.3
		1.34	1.2	1.3	1.4	18	1.05	1.3	1.2	1.3	1.3
		1.32	1.2	1.3	1.35	19	1.05	1.25	1.2	1.3	1.3
		1.32	1.2	1.3	1.3	20	1.05	1.25	1.2	1.25	1.3
	1.15	1.32	1.2	1.3	1.3	21	.05	1.25	1.2	1.25	1.3
	12	1.3	1.2	1.3	1.3	22	1.05	1.25	1.2	1.25	2.1
	1.	1.3	1.2	1.3	1 3	23	1.05	1.25	1.2	1.25	1.8
	1.	1.3	1.2	1.3	1.4	24	1.04	1.25	1.2	1.25	1.6
		1.45	1.2	1.3	1.3	25	1.42	1.25	1.2	1.25	1.6
	1.1	1.35	1.2	1.3	1.3	26	1.4	1.25	1.2	1.3	1.6
	1.08	1.35	1.2	1.3	1.3	27	1.4	1.2	1.2	1.3	1.8
	1.06	1.32	1.2	1.3	1.3	28	1.37	1.2	1.2	1.3	2.1
	1.06	1.3	1.2	1.3	1.3	29	1.34	1.2	1.2	1.3	2.1
	1.06	1.3	1.2	1.3	1.3	30	1.3	1.2	1.2	1.3	2.1
						31	1.3	.....	1.2	.....	2.0

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1896.												
	1.8	2.0	2.0	3.2	1.7	1.6	1.8	1.5	1.4	5.0	1.6	2.7
	1.8	2.0	2.0	3.0	1.7	1.5	1.8	1.5	1.4	3.3	1.6	2.55
	1.8	2.3	2.0	2.8	2.2	1.5	1.7	1.5	1.4	3.0	1.6	2.4
	1.7	2.5	2.0	2.7	2.2	1.5	1.6	1.5	1.4	2.75	1.6	2.4
	1.6	2.5	2.0	2.5	2.2	1.5	1.6	1.5	1.4	2.4	4.1	2.35
	1.5	3.15	1.9	2.5	2.2	1.5	1.7	1.45	1.4	2.3	3.5	2.1
	1.4	3.6	1.9	2.4	2.1	2.5	1.7	1.45	1.4	2.3	3.0	2.1
	1.4	3.1	1.9	2.3	2.0	2.5	1.7	1.4	1.4	2.2	2.6	2.0
	1.3	3.1	1.9	2.3	1.9	2.5	4.8	1.4	1.4	2.1	2.4	1.9
	1.3	2.7	1.9	2.2	1.9	2.0	3.2	1.4	1.4	2.0	2.3	1.8
	1.3	2.5	1.85	2.2	1.9	1.8	2.7	1.4	1.4	2.0	2.15	1.7
	1.3	2.3	1.85	2.2	1.8	1.8	2.5	1.4	1.4	1.95	2.15	1.6
	1.3	2.3	1.85	2.2	1.7	1.7	2.4	1.4	1.35	1.95	2.1	1.5
	1.2	2.8	1.85	2.15	3.0	1.6	2.3	2.0	1.35	1.9	2.1	1.5
	1.2	2.7	2.0	2.15	2.0	1.6	2.3	1.6	1.35	1.85	2.0	1.5
	1.2	2.5	2.0	2.1	1.8	1.6	2.0	1.6	1.35	1.85	2.0	1.45
	1.2	2.4	2.2	2.0	1.8	2.5	2.0	1.6	1.35	1.85	1.9	1.45
	1.2	2.3	2.2	2.0	1.7	2.2	1.7	1.5	1.35	1.85	1.9	1.45
	1.2	2.3	2.8	1.9	1.6	2.2	1.8	1.5	1.35	1.85	1.85	1.45
	1.2	2.2	4.3	1.9	1.6	2.5	1.8	1.5	1.35	1.8	1.85	1.45
	1.2	2.2	3.0	1.9	1.6	2.0	1.7	1.5	1.35	1.75	1.8	1.45
	1.2	2.2	2.6	1.8	1.6	2.0	1.7	1.5	1.3	1.7	1.8	1.45
	1.3	2.1	2.6	1.8	1.6	1.8	1.7	1.5	1.3	1.65	1.8	1.45
	4.9	2.1	2.5	1.8	1.6	1.7	1.7	1.5	1.25	1.65	1.8	1.45
	3.6	2.1	2.5	2.0	1.6	1.7	1.7	1.65	1.25	1.65	1.75	1.45
	3.0	2.0	2.4	2.0	1.6	2.0	1.7	1.5	1.25	1.65	1.7	1.45
	2.7	2.0	2.4	1.9	1.6	2.0	1.7	1.5	1.25	.....	1.65	1.45
	2.4	2.0	2.4	1.8	1.6	2.0	1.7	1.5	1.25	1.6	1.65	1.45
	2.3	2.0	2.5	1.75	1.6	1.9	1.6	1.5	9.7	1.6	2.0	1.45
	2.2	.....	3.3	1.7	1.6	1.9	1.6	1.45	17.0	1.6	3.1	1.45
	2.1	.....	3.2	.....	1.6	.....	1.5	1.45	.....	1.6	.....	1.45

Daily gage height, in feet, of South River at Port Republic, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897.												
1	1.45	1.85	2.6	2.0	1.75	1.85	1.6	1.5	1.2	1.3	1.75	1.5
2	1.45	1.85	2.5	2.0	9.3	1.8	1.65	1.5	1.2	1.3	2.8	1.5
3	1.45	1.85	2.4	2.0	4.5	1.75	1.65	1.5	1.2	1.3	2.5	1.5
4	1.45	1.85	2.4	2.0	3.3	1.75	1.6	1.5	1.2	1.3	2.1	1.5
5	1.45	1.85	2.35	2.0	3.0	1.9	1.55	1.5	1.2	1.3	2.0	1.5
6	1.45	1.95	2.3	2.1	2.8	1.75	1.55	1.5	1.2	1.3	2.0	1.5
7	1.45	5.0	2.3	2.1	2.5	1.7	1.55	1.5	1.2	1.3	1.8	1.5
8	1.45	4.1	2.3	2.1	2.5	1.65	1.55	1.45	1.2	1.3	1.75	1.5
9	1.45	3.2	2.25	2.1	2.4	1.6	1.55	1.4	1.2	1.3	1.7	1.5
10	1.45	3.05	2.25	2.1	2.3	1.55	1.55	1.4	1.2	1.3	1.7	1.5
11	1.45	2.95	2.25	2.0	2.3	1.5	1.55	1.4	1.2	1.3	1.7	1.5
12	1.45	2.9	2.25	2.0	2.3	1.5	1.55	1.4	1.3	1.3	1.65	1.5
13	1.45	3.15	2.2	1.9	3.2	1.65	1.5	1.4	1.3	1.45	1.65	1.5
14	1.45	3.15	2.3	1.9	4.8	1.65	1.5	1.4	1.3	1.45	1.65	1.5
15	1.45	3.15	2.4	1.9	3.2	1.65	1.5	1.35	1.3	1.45	1.65	1.46
16	1.45	3.4	2.6	1.9	2.85	1.65	1.5	1.35	1.3	1.45	1.65	2.4
17	1.45	3.4	2.6	1.9	2.7	1.6	1.5	1.35	1.3	1.45	1.65	2.0
18	1.45	3.2	2.6	1.85	2.5	1.6	1.5	1.3	1.3	1.45	1.65	1.9
19	1.45	3.2	2.6	1.85	2.4	1.6	1.7	1.25	1.3	1.45	1.65	1.9
20	1.45	3.1	2.6	1.8	2.35	1.65	1.6	1.2	1.3	1.45	1.65	1.85
21	1.45	3.1	2.7	1.8	2.3	1.8	1.55	1.2	1.3	1.5	1.6	1.8
22	1.45	3.6	2.5	1.8	2.25	1.7	1.5	1.2	1.3	1.5	1.55	1.8
23	1.45	6.75	2.3	1.8	2.2	1.65	1.5	1.2	1.3	1.5	1.55	1.8
24	1.65	4.1	2.35	1.8	2.2	1.6	1.5	1.2	1.3	1.5	1.55	1.8
25	1.85	3.3	2.25	1.8	2.2	1.6	1.45	1.2	1.3	1.5	1.5	1.8
26	1.85	3.2	2.15	1.8	2.15	1.6	1.4	1.2	1.3	1.5	1.5	1.8
27	1.85	3.1	2.05	1.8	2.15	1.6	1.4	1.2	1.3	1.5	1.5	1.8
28	1.85	2.8	2.1	1.8	2.1	1.6	1.4	1.2	1.3	2.0	1.5	1.8
29	1.85	.....	2.1	1.8	2.1	1.6	1.4	1.2	1.3	1.9	1.5	1.8
30	1.85	.....	2.1	1.75	2.0	1.6	1.4	1.2	1.3	1.85	1.5	1.8
31	1.85	.....	2.0	.....	1.95	.....	1.4	1.2	.....	1.75	.....	1.8
1898.												
1	1.8	2.0	1.5	2.25	2.1	1.75	1.6	2.1	1.6	1.35	2.5	1.9
2	1.8	2.0	1.5	2.25	2.05	1.65	1.6	2.0	1.5	1.35	2.35	1.8
3	1.8	2.0	1.6	2.25	2.0	1.6	1.55	2.0	1.5	1.35	2.2	1.8
4	1.75	2.0	1.6	2.2	2.0	1.6	1.55	2.0	1.5	1.35	2.15	2.5
5	1.75	2.0	1.6	2.15	1.9	1.6	1.55	4.4	1.5	1.75	2.1	4.0
6	1.65	1.95	1.6	2.15	2.2	1.6	1.55	3.0	1.5	3.0	2.1	3.0
7	1.65	1.9	1.6	2.15	4.1	1.6	1.55	2.4	1.5	2.9	2.05	2.9
8	1.6	1.85	1.6	2.1	5.0	1.6	1.55	2.4	1.5	2.6	2.0	2.7
9	1.6	1.8	1.6	2.0	4.1	1.55	1.55	2.3	1.5	2.3	2.0	2.5
10	1.6	1.75	1.6	2.1	3.5	1.55	1.5	6.4	1.5	2.15	2.0	2.4
11	1.6	1.7	1.6	2.05	3.1	1.5	1.45	6.6	1.5	2.0	2.0	2.35
12	1.55	1.7	1.6	2.0	2.9	1.85	1.4	3.6	1.5	1.95	2.0	2.3
13	1.55	1.65	1.6	2.0	2.6	1.75	1.4	3.0	1.5	1.9	2.0	2.3
14	1.55	1.6	1.6	2.0	2.6	1.65	1.4	3.0	1.5	1.8	1.9	2.25
15	1.55	1.55	1.6	2.75	2.5	1.55	1.6	2.8	1.5	1.8	1.9	2.2
16	1.55	1.5	1.6	3.0	2.4	1.75	1.6	2.6	1.5	1.8	1.9	2.15
17	1.55	1.5	1.85	2.8	2.4	1.75	1.6	2.4	1.5	1.75	1.9	2.1
18	1.55	1.5	1.85	2.7	2.3	1.75	1.6	2.3	1.5	1.75	1.85	2.1
19	1.55	1.5	1.85	2.5	2.2	1.75	1.6	2.3	1.5	7.5	1.85	2.1
20	1.55	1.5	1.8	2.4	2.1	1.75	1.6	2.2	1.5	3.8	2.15	2.0
21	1.55	1.5	1.8	2.25	2.0	1.75	1.6	2.2	1.5	3.8	2.1	2.0
22	1.55	1.5	1.8	2.15	2.6	1.75	1.6	2.2	1.5	7.6	2.1	2.0
23	2.0	1.5	1.8	2.1	2.0	1.7	1.6	2.2	1.65	4.5	2.1	2.6
24	2.0	1.5	1.9	2.1	2.0	1.7	1.7	2.1	1.65	4.0	2.1	2.6
25	2.0	1.5	1.9	2.2	1.9	1.7	1.7	2.0	1.6	3.1	2.1	2.5
26	2.0	1.5	1.9	2.5	1.9	1.7	1.7	1.9	1.5	3.0	2.1	2.45
27	2.0	1.5	2.0	2.3	1.85	1.65	1.7	1.8	1.45	2.8	2.1	2.4
28	2.0	1.5	2.0	2.25	1.8	1.6	1.7	1.7	1.4	2.6	2.1	2.35
29	2.0	.....	2.0	2.2	1.8	1.6	1.7	1.6	1.35	2.5	2.1	2.3
30	2.0	.....	2.0	2.1	1.8	1.6	1.7	1.6	1.35	2.5	2.0	2.3
31	2.0	.....	2.2	.....	1.8	.....	2.1	1.6	.....	2.5	.....	2.3

Daily gage height, in feet, of South River at Port Republic, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	Day.	Jan.	Feb.	Mar.	Apr.
1899.					1899.				
1	2.5	2.1	4.0	2.5	17	2.5	2.6	3.2	.....
2	2.5	2.1	3.6	.....	18	2.4	2.6	2.9	.....
3	2.4	2.1	3.5	.....	19	2.2	2.8	3.2	.....
4	2.3	2.1	5.1	.....	20	2.2	3.0	3.7	.....
5	2.3	2.1	12.0	.....	21	2.2	3.5	3.5	.....
6	3.4	2.1	6.7	.....	22	2.2	5.0	3.2	.....
7	5.0	2.1	5.5	.....	23	2.2	5.6	3.1	.....
8	3.8	2.2	4.0	.....	24	2.2	4.1	2.9	.....
9	3.6	2.2	3.6	.....	25	2.2	3.5	2.8	.....
10	3.0	2.3	3.9	.....	26	2.2	4.4	2.8	.....
11	2.9	2.3	3.7	.....	27	2.2	6.5	2.8	.....
12	2.75	2.3	3.6	.....	28	2.2	5.3	2.7	.....
13	2.6	2.3	3.4	.....	29	2.2	.....	2.7	.....
14	2.6	2.4	3.3	.....	30	2.2	.....	2.6	.....
15	2.6	2.5	3.4	.....	31	2.1	.....	2.5	.....
16	2.6	2.6	3.3	.....					

Rating table for South River at Port Republic, Va., from August 5, 1895, to April 1, 1899.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.3	95	2.2	350	3.8	1,535	5.2	2,575
1.4	105	2.4	495	4.0	1,685	5.4	2,720
1.5	120	2.6	645	4.2	1,835	5.6	2,870
1.6	140	2.8	795	4.4	1,980	5.8	3,015
1.7	160	3.0	945	4.6	2,125	6.0	3,165
1.8	180	3.2	1,090	4.8	2,275	6.5	3,535
1.9	210	3.4	1,240	5.0	2,425	7.0	3,905
2.0	250	3.6	1,390				

[a] This rating table is strictly applicable only for open-channel conditions. It is not well defined.

Estimated monthly discharge of South River at Port Republic, Va.

[Drainage area, 246 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1895.					
August 6–31	105	70	80	0.33	0.32
September	112	85	94	.38	.43
October	85	85	85	.35	.40
November	95	85	93	.38	.43
December	290	95	136	.55	.63
1896.					
January	2,350	85	305	1.24	1.43
February	1,390	250	517	2.10	2.19
March	1,905	195	473	1.11	1.28
April	1,090	160	375	1.52	1.70
May	945	140	218	.89	1.02
June	570	120	255	1.04	1.16
July	2,275	120	322	1.31	1.51
August	250	105	123	.50	.58
September	9,200	90	597	2.43	2.71
October	2,425	140	362	1.47	1.69
November	1,760	140	376	1.53	1.71
December	720	112	208	.85	.98
The year	9,200	85	344	1.33	17.96

Estimated monthly discharge of South River at Port Republic, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1897.					
January	195	112	131	.53	.61
February	3,717	195	1,072	4.36	4.54
March	720	250	459	1.87	2.16
April	290	170	211	.86	.96
May	5,607	170	797	3.24	3.74
June	210	120	152	.62	.69
July	160	105	126	.51	.59
August	120	85	103	.42	.48
September	95	85	91	.37	.41
October	250	95	119	.48	.55
November	795	120	192	.78	.87
December	495	112	166	.67	.77
The year	5,607	85	301	1.23	16.36
1898.					
January	250	130	175	.71	.82
February	250	120	162	.66	.69
March	350	120	177	.72	.83
April	945	250	408	1.66	1.85
May	2,425	180	561	2.28	2.63
June	195	120	153	.62	.69
July	290	105	142	.58	.67
August	3,605	140	690	2.80	3.23
September	150	100	121	.49	.55
October	4,345	100	835	3.39	3.91
November	570	195	282	1.15	1.28
December	1,685	180	484	1.97	2.27
The year	4,345	100	349	1.42	19.42
1899.					
January	2,425	290	638	2.59	2.99
February	3,535	290	964	3.92	4.08
March	7,700	570	1,525	6.20	7.15

NORTH RIVER BASIN.

COOKS CREEK AT MOUNT CRAWFORD, VA.

Cooks Creek rises near Harrisonburg, in Rockingham County, Va., and flows southwestward and southeastward into North River near Mount Crawford.

The gaging station was established July 1, 1905, by N. C. Grover, in connection with the investigation of stream pollution in the Shenandoah Valley. It was discontinued July 16, 1906. It is located at the upper highway bridge across Cooks Creek, three-fourths of a mile from Mount Crawford.

The channel is straight for 200 feet above and 100 feet below the station. The current is very sluggish at low water. Both banks are low and liable to overflow during high water, but all the water passes beneath the bridge. The bed of the stream is composed of mud and gravel. The stream is polluted by tanneries.

Discharge measurements were made from the side of the bridge to which the gage is attached, or by wading a short distance below, at a point where the velocity is greater.

A standard chain gage is fastened to the outside of the downstream guard rail of the bridge. The length of the chain from the end of the weight to the outer edge of the ring is 14.38 feet. The gage was read once each day by S. H. Craun. Bench mark No. 1 is a nail driven vertically into a root on the downstream side of a large tree 150 feet below the gage, on the left bank. Its elevation is 4.24 feet above the gage datum.

Estimates at this station are within 10 per cent of the true flow between gage heights 1.9 and 2.7 feet. Above and below these stages the estimates are liable to error of 10 to 25 per cent. The flow may have been slightly affected by ice conditions during the winter of 1905–6.

Discharge measurements of Cooks Creek at Mount Crawford, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
July 1	2.10	20	April 10	2.32	32.4
December 30[a]	2.06	22.6			

[a] Measurement made by wading.

Daily gage height, in feet, of Cooks Creek at Mount Crawford, Va.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.							1905.						
1	2.1	2.2	1.8	1.8	1.7	1.8	17	2.3	1.9	1.8	1.7	1.7	1.7
2	2.1	2.2	1.9	1.8	1.7	1.8	18	2.2	2.0	1.8	1.7	1.7	1.7
3	2.0	2.1	1.9	1.8	1.7	2.0	19	2.2	1.9	1.8	1.8	1.8	1.7
4	2.0	2.1	1.8	1.8	1.7	1.8	20	2.4	2.0	1.8	1.7	1.8	1.7
5	5.5	2.1	1.8	1.8	1.7	1.8							
							21	2.1	2.0	1.8	1.7	1.8	2.9
6	3.3	2.1	1.8	1.8	1.7	1.8	22	2.2	1.9	1.8	1.7	1.8	2.6
7	2.9	2.0	1.7	1.7	1.7	1.8	23	2.4	1.9	1.8	1.7	1.8	2.4
8	2.4	2.0	1.8	1.7	1.7	1.8	24	2.3	1.8	1.8	1.7	1.8	2.3
9	2.2	2.0	1.8	1.7	1.7	1.8	25	2.2	1.9	1.7	1.8	1.8	2.1
10	2.1	2.0	1.8	1.7	1.7	1.8							
							26	2.2	2.1	1.7	2.0	1.8	2.0
11	2.5	2.0	1.8	1.7	1.7	1.8	27	2.2	2.0	1.8	1.8	1.8	2.0
12	2.1	2.1	1.8	1.7	1.8	1.8	28	2.0	2.0	1.7	1.8	1.8	2.0
13	2.3	2.1	1.8	1.7	1.8	1.7	29	2.0	2.0	1.7	1.8	1.8	2.3
14	2.2	2.1	1.8	1.7	1.7	1.7	30	3.1	1.9	1.8	1.7	1.8	2.1
15	2.8	2.0	1.8	1.7	1.7	1.7	31	2.4	1.9	.....	1.7	.....	2.2
16	2.4	2.0	1.8	1.7	1.7	1.7							

Daily gage height, in feet, of Cooks Creek at Mount Crawford, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.												
1	2.05	2.0	2.0	2.5	2.1	2.0	2.1					
2	2.05	2.0	2.0	2.4	2.1	2.0	2.1					
3	2.05	1.8	2.0	2.3	2.1	2.0	2.1					
4	3.0	2.0	2.4	2.3	2.1	2.0	2.1					
5	2.5	2.0	2.2	2.2	2.1	2.0	2.0					
6	2.3	2.1	2.1	2.3	2.	1.9	2.0					
7	2.3	2.0	2.1	2.2	2.2	1.9	2.0					
8	2.2	2.0	2.1	2.2	2.2	1.9	2.0					
9	2.2	2.0	2.1	2.3	2.1	1.9	2.0					
10	2.1	2.0	2.1	2.3	2.	1.9	2.0					
11	2.1	2.1	2.1	2.2	2.1	1.9	3.0					
12	2.1	2.0	2.1	2.2	2.0	1.9	2.1					
13	2.1	2.0	2.05	2.2	2.	.8	2.0					
14	2.3	2.0	2.4	2.2	2.	1.8	2.0					
15	2.3	2.0	2.6	2.5	2.0	1.8	2.0					
16	2.2	1.9	2.5	2.4	2.0	1.8						
17	2.2	2.0	2.4	2.3	2.0	2.0						
18	2.2	2.0	2.3	2.2	2.0	2.0						
19	2.1	1.9	2.4	2.2	2.0	2.0						
20	2.1	1.9	2.3	2.2	2.0	2.5						
21	2.1	2.0	2.3	2.2	1.9	2.1						
22	2.1	2.0	2.3	2.2	1.9	2.2						
23	2.3	2.0	2.3	2.2	1.9	2.1						
24	2.3	1.8	2.3	2.1	2.0	2.0						
25	2.2	2.0	2.3	2.1	2.0	2.0						
26	2.1	2.0	2.3	2.2	2.0	2.1						
27	2.1	2.0	2.6	2.2	2.0	3.0						
28	2.2	2.0	2.5	2.1	2.0	2.0						
29	2.2	.....	2.5	2.1	2.0	2.2						
30	2.1	.....	2.4	2.1	2.0	2.1						
31	2.1	.....	2.5	.....	2.0	.....						

Rating table for Cooks Creek at Mount Crawford, Va., from July 1, 1905, to July 15, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.70	10	2.70	52	3.70	126	4.70	235
1.80	13	2.80	58	3.80	135	4.80	248
1.90	16	2.90	64	3.90	144	4.90	261
2.00	19	3.00	71	4.00	154	5.00	274
2.10	23	3.10	78	4.10	164	5.10	288
2.20	27	3.20	85	4.20	175	5.20	302
2.30	31	3.30	92	4.30	186	5.30	316
2.40	36	3.40	100	4.40	198	5.40	331
2.50	41	3.50	108	4.50	210	5.50	346
2.60	46	3.60	117	4.60	222		

[a] This table is strictly applicable only for open-channel conditions. It is based on two discharge measurements made during 1905-6. It is not well defined. Estimates based on this table are only roughly approximate.

Estimated monthly discharge of Cooks Creek at Mount Crawford, Va.

[Drainage area, 41 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
	346	19	43.8	1.07	1.23
	27	13	19.7	.480	.553
r	16	10	12.7	.310	.346
	19	10	11.4	.278	.320
r	13	10	11.4	.278	.310
	64	10	18.7	.456	.526
1906.					
	71	21	27.5	.671	.774
	23	13	18.5	.451	.470
	46	19	30.6	.746	.860
	41	23	28.7	.700	.781
	27	16	20.6	.502	.579
	71	13	21.0	.512	.571
	71	19	23.8	.580	.324

LEWIS CREEK NEAR STAUNTON, VA.

is Creek rises in the central part of Augusta County, Va., about
s southwest of Staunton, and flows northeastward into Middle

gaging station was established June 30, 1905, by N. C. Grover,
ıection with the investigation of stream pollution in the Shenan-
'alley. It was discontinued July 16, 1906. It is located at the
› bridge across Lewis Creek, on the property of William Glenn,
; from Staunton.

chanel is straight for 300 feet above and below the station.
rrent is sluggish. Both banks are about 5 feet high and do not
w, except during very high water. The bed of the stream is
sed of soft mud. There is but one channel at all stages. The
is composed almost wholly of sewage from the city of Staunton,
very shallow at ordinary stages.

harge measurements were made from the downstream side of
dge, the initial point for soundings being the gatepost near the
l of the bridge.

ɪrtical staff gage, graduated to feet and tenths, is fastened to a
'eet downstream from the bridge. The gage was read once each
Ashby Glenn. Bench mark No. 1 is a nail in the locust tree to
the gage is attached, 1 foot above the ground, on the upstream
Its elevation is 7.56 feet above the zero of the gage.

r to about May 27, 1906, the estimates for this station are
te within 5 to 10 per cent for gage heights 0.45 to 0.9 foot.
and below these stages the error may be as high as 15 per cent.
ıtes after about May 27, 1906, may be in error 15 to 20 per cent.
›w was probably not affected by ice conditions during 1905–6.

Discharge measurements of Lewis Creek near Staunton, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
June 30	0.51	3.8	April 10	0.83	12.5
December 29	.63	6.2	June 14	.55	6.6

Daily gage height, in feet, of Lewis Creek near Staunton, Va.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.							1905.						
1	0.65	0.45	0.5	0.4	0.4	0.5	17	0.5	0.45	0.5	0.5	0.45	0.5
2	.88	.55	.4	.4	.5	.5	18	.5	.6	.45	.45	.75	.5
3	.7	.45	.45	.65	.5	.6	19	.55	.5	.45	.45	.45	.5
4	.65	.45	.4	.4	.5	.4	20	.4	.45	.45	.6	.4	.45
5	.5	.6	.45	.4	.5	.5	21	.5	.45	.45	.6	.45	.4
6	.5	.5	.45	.35	.6	.5	22	1.05	.45	.5	.5	.55	.45
7	.7	.5	.45	.4	.65	.45	23	.6	.55	.45	.6	.35	.45
8	.6	.45	.45	.4	.5	.5	24	.6	.45	.45	.7	.35	.5
9	.55	.5	.45	.6	.4	.5	25	.55	.5	.45	.65	.5	.5
10	.5	.45	.45	.5	.4	.4	26	.5	.5	.4	.6	.5	.5
11	.5	.35	.45	1.0	.55	.4	27	.6	.5	.4	.6	.5	.45
12	1.1	.45	.45	.8	.5	.4	28	.45	.5	.4	.6	.45	.65
13	.7	.45	.5	.7	.6	.45	29	.5	.5	.4	.4	.4	.55
14	.5	.45	.6	.5	.6	.5	30	.45	.4	.4	.45	.4	.5
15	.55	.5	.6	.4	.5	.6	31	.5	.5	.....	.5	.....	.4
16	.55	.5	.5	.4	.5	.65							

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.												
1	0.54	0.49	0.74	0.74	0.48	0.54	0.64	.....	.....	.....	.....	.....
2	.43	.53	.70	.70	.53	.53	.53	.....	.....	.....	.....	.....
3	.54	.60	.71	.64	.60	.54	.54	.....	.....	.....	.....	.....
4	1.43	.53	.53	.49	.49	.58	.53	.....	.....	.....	.....	.....
5	.94	.54	.64	.54	.53	.59	.49	.....	.....	.....	.....	.....
6	.83	.53	.59	.48	.54	.48	.53	.....	.....	.....	.....	.....
7	.64	.49	.54	.44	.53	.54	.64	.....	.....	.....	.....	.....
8	.53	.53	.53	.57	.54	.53	.53	.....	.....	.....	.....	.....
9	.49	.44	.71	.44	.43	.49	.54	.....	.....	.....	.....	.....
10	.43	.48	.53	.83	.49	.53	.48	.....	.....	.....	.....	.....
11	.59	.44	.54	.84	.48	.44	.44	.....	.....	.....	.....	.....
12	.48	.53	.59	.73	.49	.53	.48	.....	.....	.....	.....	.....
13	.69	.49	.74	.79	.43	.54	.53	.....	.....	.....	.....	.....
14	.53	.59	.63	.63	.44	.53	.64	.....	.....	.....	.....	.....
15	.59	.54	1.04	.74	.48	.49	.43	.....	.....	.....	.....	.....
16	.53	.48	.83	.63	.49	.63	.....	.....	.....	.....	.....	.....
17	.44	.54	.84	.74	.33	.49	.....	.....	.....	.....	.....	.....
18	.48	.53	.83	.53	.34	.43	.....	.....	.....	.....	.....	.....
19	.59	.49	.84	.49	.48	.49	.....	.....	.....	.....	.....	.....
20	.53	.43	.78	.53	.44	.53	.....	.....	.....	.....	.....	.....
21	.74	.49	.74	.49	.43	.49	.....	.....	.....	.....	.....	.....
22	.63	.53	.70	.53	.49	.43	.....	.....	.....	.....	.....	.....
23	.74	.54	.64	.64	.38	.44	.....	.....	.....	.....	.....	.....
24	.63	.43	.63	.63	.34	.93	.....	.....	.....	.....	.....	.....
25	.54	.54	.64	.54	.33	1.94	.....	.....	.....	.....	.....	.....
26	.48	.53	.59	.54	.94	1.83	.....	.....	.....	.....	.....	.....
27	.54	.49	.54	.59	1.18	.94	.....	.....	.....	.....	.....	.....
28	.63	.43	1.13	.49	1.64	.73	.....	.....	.....	.....	.....	.....
29	.54	.....	.84	.63	1.13	.54	.....	.....	.....	.....	.....	.....
30	.48	.....	.93	.64	.64	.53	.....	.....	.....	.....	.....	.....
31	.44	.....	1.24	.....	.58	.....	.....	.....	.....	.....	.....	.....

Rating tables for Lewis Creek near Staunton, Va.

JULY 1, 1905, TO MAY 27, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.30	1.0	0.65	6.8	1.00	18.9	1.35	39.0
.35	1.4	.70	8.2	1.05	21.0	1.40	42.5
.40	1.9	.75	9.7	1.10	23.5	1.45	46.5
.45	2.6	.80	11.3	1.15	26.0	1.50	50.5
.50	3.4	.85	13.0	1.20	29.0	1.55	54.5
.55	4.4	.90	14.9	1.25	32.0	1.60	59.0
.60	5.5	.95	16.8	1.30	35.5	1.65	63.5

MAY 28, 1906, TO JULY 15, 1906.[b]

0.25	1.3	0.60	7.9	0.95	20.5	1.50	55
.30	1.8	.65	9.4	1.00	23.0	1.60	63
.35	2.5	.70	11.0	1.10	28.5	1.70	71
.40	3.3	.75	12.7	1.20	34.5	1.80	79
.45	4.2	.80	14.5	1.30	41	1.90	88
.50	5.3	.85	16.3	1.40	48	2.00	97
.55	6.5	.90	18.3				

[a] This table is strictly applicable only for open-channel conditions. It is based on three discharge measurements made during 1905. It is fairly well defined between gage heights 0.5 and 0.8 foot.
[b] This table is based on one discharge measurement made during 1906 and on the form of the preceding curve.

Estimated monthly discharge of Lewis Creek near Staunton, Va.

[Drainage area, 20 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
uly	24	1.9	5.98	0.299	0.345
ugust	5.5	1.4	3.15	.158	.182
ptember	5.5	1.9	2.76	.138	.154
ctober	19	1.4	4.58	.229	.264
ovember	9.7	1.4	3.46	.173	.193
ecember	6.8	1.9	3.34	.167	.192
1906.					
anuary	45	2.3	6.58	.329	.379
ebruary	5.5	2.3	3.61	.180	.187
arch	31	4.0	9.70	.485	.559
pril	13	2.3	6.06	.303	.338
ay	66	1.2	7.41	.370	.427
ne	92	3.8	12.3	.615	.686
ly 1–15	9.1	3.8	6.17	.308	.172

NORTH RIVER AT PORT REPUBLIC, VA.

North River rises in the Shenandoah Mountains in the northwestern rt of Augusta County, Va., and flows in a general easterly and southsterly direction to Port Republic, Rockingham County, Va., where unites with South River to form South Fork of the Shenandoah. s drainage area is 805 square miles. It is fed by numerous springs d is utilized to a considerable extent by mills of various kinds.

An important tributary is Middle River, which has been considered some authorities as the main stream, North River being regarded

as the tributary. Middle River rises on Little North Mountain, in the southern part of Augusta County, and flows in a general northeasterly direction, uniting with North River 4 miles above Port Republic. Its drainage area is 365 square miles. It is fed by numerous springs and is utilized to a considerable extent by mills of various kinds.

The gaging station at Port Republic was established August 6, 1895, and was discontinued April 1, 1899. It was located at the highway bridge, about 500 feet above the junction of North River with South River. Measurements were made from the downstream side of the bridge. The banks are high and not subject to overflow. The bed is very rough, but permanent. The current is broken and uneven at low stages. A dam about 200 feet above the bridge controls the flow at low stages.

Estimates previously published for North River at Port Republic have not been revised. They are probably within 15 per cent of the true flow. Ice conditions probably do not affect the flow at this station.

Discharge measurements of North River at Port Republic, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1895.	*Feet.*	*Second-feet.*	1897.	*Feet.*	*Second-feet.*
August 6	2.18	375	April 19	2.60	712
August 29[a]	2.09	258	June 1	2.60	552
1896.			July 24	2.30	431
June 5	2.20	427	November 7	2.00	245
July 31	2.48	428	1899.		
July 31[b]	2.46	335	March 11	4.80	3,423
1897.					
March 23	3.54	1,466			

[a] Result obtained by deducting the discharge of South River, 87 second-feet, from total discharge of South Fork of Shenandoah River, 345 second-feet, measured below the junction.

[b] Result obtained as on August 29, 1895, by deducting 139 second-feet, discharge of South River, from 474 second-feet, discharge of South Fork.

Daily gage height, in feet, of North River at Port Republic, Va.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1895.						1895.					
1		2.03	1.9	1.75	1.85	17	2.07	1.9	1.75	2.0	1.8
2		2.03	1.9	1.75	1.9	18	2.07	1.9	1.75	2.0	1.8
3		2.0	1.9	1.85	1.9	19	2.07	1.9	1.75	2.0	1.8
4		2.0	1.9	1.85	1.85	20	2.07	1.9	1.75	1.9	1.8
5		2.0	1.9	1.85	1.8						
						21	2.05	1.9	1.75	1.9	1.8
6	2.2	2.0	1.9	1.85	1.85	22	2.05	1.9	1.75	1.85	2.1
7	2.2	2.0	1.9	1.85	1.85	23	2.05	1.9	1.75	1.85	1.9
8	2.15	2.0	1.85	1.85	1.85	24	2.05	1.9	1.75	.....	1.8
9	2.15	4.3	1.85	1.85	1.9	25	2.4	1.9	1.75	.....	1.8
10	2.15	2.2	1.85	1.85	1.8						
						26	2.3	1.9	1.75	.....	1.8
11	2.15	2.1	1.85	1.9	1.8	27	2.2	1.9	1.75	.....	1.9
12	2.08	2.1	1.85	1.9	1.8	28	2.15	1.9	1.75	.....	2.4
13	2.08	2.0	1.85	1.9	1.8	29	2.09	1.9	1.75	1.85	2.45
14	2.08	2.0	1.85	1.9	1.8	30	2.05	1.9	1.75	1.85	2.4
15	2.08	2.0	1.85	2.0	1.8	31	2.03	.....	1.75	.....	2.5
16	2.07	2.0	1.75	2.0	1.8						

ily gage height, in feet, of North River at Port Republic, Va.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	3.0	2.5	2.6	5.4	2.32	2.42	2.8	2.43	2.0	7.5	2.35	4.4
	2.7	2.5	2.6	5.0	2.52	2.32	2.7	2.43	1.95	4.5	2.35	3.5
	2.5	2.8	2.6	4.6	2.52	2.32	2.7	2.55	1.9	4.0	2.35	3.3
	2.4	3.8	2.6	4.2	3.32	2.22	2.6	2.45	1.9	3.5	2.35	3.3
	2.4	3.8	2.6	4.0	3.32	2.2	2.6	2.4	1.9	3.3	4.7	3.25
	2.4	5.0	2.5	3.6	3.32	2.2	2.8	2.4	1.85	3.2	6.0	3.1
	2.4	5.7	2.5	3.5	3.12	4.5	2.8	2.3	1.85	3.1	4.3	3.05
	2.3	4.5	2.5	3.5	2.92	3.0	2.8	2.3	1.8	3.0	3.6	2.9
	2.3	4.1	2.5	3.4	2.72	2.6	7.5	2.3	1.8	2.9	3.3	2.8
	2.3	3.7	2.5	3.3	2.72	2.5	5.3	2.25	1.75	2.8	3.3	2.7
	2.3	3.5	2.4	3.3	2.72	2.3	3.9	2.2	1.7	2.65	3.2	2.65
	2.3	3.3	2.4	3.2	2.62	2.3	3.6	2.2	1.7	2 55	3.0	2.6
	2.3	3.3	2.4	3.2	2.52	2.2	3.3	2.2	1.7	2.5	2.8	2.55
	2.2	5.2	2.4	3.0	5.82	2.2	3.0	3.6	1.7	2.5	2.8	2.55
	2.2	4.7	2.6	3.0	3.82	2.2	3.3	2.7	2.0	2.5	2.7	2.5
	2.1	3.8	2.6	.....	3.22	2.2	3.0	2.7	1.9	2.5	2.7	2.5
	2.1	3.6	2.8	.....	3.02	2.5	3.1	3.0	1.8	2.5	2.65	2.45
	2.0	3.1	3.2	.....	2.82	2.4	2.7	2.4	1.8	2.45	2.65	2.45
	2.0	3.0	4.8	.....	2.62	2.4	2.7	2.3	1.8	2.45	2.6	2.45
	2.0	2.7	7.2	.....	2.62	3.3	2.7	2.25	1.7	2.4	2.6	2.45
	2.0	2.7	5.0	.....	2.62	3.0	2.6	2.25	1.7	2.4	2.55	2.45
	2.0	2.7	4.8	.....	2.62	2.9	2.5	2.25	1.7	2.35	2.5	2.45
	2.1	2.7	4.0	.....	2.62	2.5	2.5	2.2	1.7	2.35	2.5	2.45
	6.15	2.7	3.8	.....	2.52	2.4	2.5	2.2	1.65	2.35	2.45	2.45
	5.3	2.7	3.5	.....	2.52	2.4	3.0	2.4	1.65	2.35	2.4	2.4
	4.0	2.6	3.5	.....	2.52	3.2	2.7	2.2	1.65	2.35	2.4	2.4
	3.3	2.6	3.5	.....	2 52	3.0	2.7	2.2	1.65	.....	2.35	2.4
	3.0	2.6	3.5	2.22	2.42	3.0	2.6	2.15	1.65	2.35	2.35	2.4
	2.8	2.6	4.4	2.22	2.42	2.9	2.6	2.15	7.2	2.35	3.0	2.4
	2.6	.....	6.5	2.22	2.42	2.9	2.5	2.1	18.0	2.35	5.5	2.4
	2.5	.....	5.9	.....	2.42	.....	2.45	2.1	.....	2.35	.....	2.35
	2.35	2.35	3.6	2.7	2.4	2.6	2.35	2.15	2.0	1.8	2.2	1.85
	2.35	2.35	3.5	2.7	11.5	2.55	2.45	2.15	2.0	1.8	2.0	1.85
	2.35	2.35	3.4	2.6	7.3	2.5	2.45	2.15	2.0	1.8	2.6	1.85
	2.35	2.35	3.4	2.6	5.15	2.5	2.4	2.15	2.0	1.8	2.0	1.85
	2.35	2.35	3.35	2.6	4.3	3.0	2.35	2.15	1.95	1.8	2.0	2.0
	2.3	2.55	3.3	2.9	3.8	2.85	2.25	2.15	1.95	1.8	2.0	2.0
	2.3	7.0	3.3	2.9	3.5	2.6	2.2	2.1	1.9	1.8	2.0	1.95
	2.3	5.5	3.3	2.9	3.3	2.55	2.4	2.1	1.9	1.8	1.95	1.95
	2.3	4.8	3.25	2.9	3.1	2.5	2.3	2.1	1.9	1.8	1.9	1.9
	2.3	4.3	3.25	3.0	3.0	2.5	2.2	2.1	1.85	1.8	1.9	1.85
	2.3	4.0	3.25	3.0	3.0	2.45	2.15	2.05	1.85	1.8	1.9	1.85
	2.3	3.9	3.25	3.0	3.0	2.4	2.5	2.05	1.85	1.8	1.85	1.85
	2.3	5.45	3.2	2.9	4.9	2.4	2.4	2.05	1.85	2.0	1.85	1.85
	2.2	4.7	3.3	2.9	7.5	2.4	2.4	2.05	1.85	2.0	1.8	1.85
	2.25	5.0	3.5	2.9	5.2	2.4	2.3	2.0	1.85	2.0	1.8	2.65
	2.25	5.3	3.5	2.9	4.4	2.4	2.2	2.0	1.85	1.95	1.9	2.45
	2.25	5.2	3.7	2.9	4.0	2.4	2.2	2.0	1.85	1.95	1.9	2.25
	2.25	4.6	3.7	2.8	3.6	2.4	2.15	2.0	1.85	1.95	1.9	2.1
	2.25	4.5	3.7	2.65	3.45	2.4	3.5	2.0	1.8	1.95	1.9	2.25
	2.25	4.3	3.7	2.6	3.25	2.5	3.5	2.0	1.8	1.95	1.9	2.25
	2.25	4.2	3.9	2.55	3.15	2.45	2.5	.....	1.8	2.0	1.85	2.25
	2.25	4.8	3.6	2.5	3.1	2.4	2.4	2.0	1.8	2.0	1.85	2.25
	2.25	9.85	3.35	2.5	3.0	2.4	2.35	2.0	1.8	2.0	1.85	2.25
	2.25	6.7	3.4	2.5	2.95	2.4	2.35	2.0	1.8	2.0	1.85	2.25
	2.25	5.4	3.3	2.5	2.9	2.4	2.3	2.0	1.8	2.0	1.85	2.25
	2.25	4.5	3.2	2.5	2.85	2.4	2.25	2.0	1.8	2.0	1.85	2.25
	2.25	4.4	3.1	2.45	2.8	2.35	2.2	2.0	1.8	2.0	1.85	2.25
	2.25	3.8	3.0	2.45	2.75	2.35	2.15	2.0	1.8	2.1	1.85	2.25
	2.25	.....	2.9	2.45	2.7	2.35	2.15	2.0	1.8	2.05	1.85	2.25
	2.25	.....	2.8	2.4	2.65	2.35	2.15	2.0	1.8	1.95	1.85	2.2
	2.35	.....	2.7	.....	2.6	.....	2.15	2.0	.....	1.95	.....	2.15

Daily gage height, in feet, of North River at Port Republic, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898.												
1	2.15	2.7	2.1	3.85	2.65	2.35	2.2	4.25	2.6	2.4	3.0	2.4
2	2.15	2.7	2.1	3.5	2.6	2.3	2.2	4.25	2.5	2.4	2.8	2.3
3	2.15	2.7	2.1	3.3	2.5	2.15	2.2	4.0	2.5	2.4	2.65	2.3
4	2.1	2.7	2.1	3.15	2.45	2.15	2.2	4.5	2.5	2.4	2.6	2.0
5	2.1	2.7	2.1	3.0	2.4	2.15	2.2	8.0	2.5	3.0	2.6	2.0
6	2.1	2.65	2.1	2.9	3.0	2.1	2.2	5.0	2.5	2.9	2.6	2.0
7	2.05	2.65	2.1	2.9	6.4	2.1	2.2	5.0	2.5	2.8	2.5	2.6
8	2.05	2.6	2.1	2.8	7.25	2.1	2.2	4.6	2.5	2.6	2.5	2.3
9	2.0	2.5	2.1	2.6	6.3	2.1	2.2	4.0	2.5	2.4	2.45	2.0
10	2.6	2.4	2.1	2.75	5.0	2.0	2.15	9.0	2.5	2.25	2.4	2.9
11	2.55	2.3	2.1	2.75	4.0	2.0	2.1	9.0	2.5	2.1	2.4	2.8
12	2.5	2.2	2.1	2.75	3.6	2.6	2.1	7.0	2.5	2.1	2.4	2.7
13	2.45	2.2	2.1	2.75	3.3	2.5	2.0	6.0	2.5	2.1	2.35	2.6
14	2.45	2.15	2.1	2.75	3.2	2.35	2.0	6.0	2.5	2.0	2.35	2.6
15	2.45	2.15	2.1	4.15	3.0	2.2	2.1	6.0	2.5	2.0	2.3	2.8
16	2.45	2.1	2.1	5.2	2.8	4.2	2.1	4.5	2.5	2.0	2.3	2.5
17	2.45	2.1	2.25	4.5	2.8	3.4	2.25	4.2	2.5	2.0	2.25	2.5
18	2.45	2.1	2.8	4.0	2.7	3.0	2.5	4.0	2.5	2.0	2.2	2.4
19	2.55	2.1	2.95	3.5	2.6	3.0	2.4	4.0	2.5	9.5	2.15	2.3
20	2.55	2.1	2.85	3.2	2.6	3.0	2.3	3.6	2.5	5.0	2.6	2.3
21	2.55	2.1	2.75	3.0	2.6	3.0	2.3	3.3	2.5	5.0	2.6	2.3
22	2.55	2.1	2.75	2.9	3.35	2.9	2.3	3.2	2.5	10.0	2.6	2.3
23	2.7	2.1	2.75	2.75	3.3	2.8	2.3	3.1	2.75	6.5	2.6	4.0
24	2.8	2.1	2.75	2.75	3.2	2.65	3.0	3.1	2.75	5.0	2.6	4.3
25	2.8	2.1	2.85	2.75	3.0	2.5	2.8	3.0	2.65	3.8	2.6	3.6
26	2.8	2.1	2.9	2.75	2.9	2.5	2.7	2.9	2.65	3.65	2.6	2.3
27	2.8	2.1	3.0	2.75	2.75	2.5	3.5	2.8	2.6	3.5	2.55	2.0
28	2.7	2.1	3.0	2.7	2.65	2.4	4.75	2.7	2.6	3.3	2.5	2.8
29	2.7	.....	3.0	2.65	2.65	2.4	5.0	2.7	2.5	3.15	2.5	2.6
30	2.7	.....	3.3	2.65	2.5	2.4	5.0	2.6	2.4	3.15	2.5	2.6
31	2.7	.....	4.2	.....	2.4	.....	4.5	2.6	.....	3.15	.....	2.6

	Jan.	Feb.	Mar.	Apr.		Jan.	Feb.	Mar.	Apr.
1899.					1899.				
1	2.75	2.3	7.1	3.0	17	2.7	3.0	4.0	.....
2	2.75	2.3	5.5	.....	18	2.7	3.0	3.7	.....
3	2.7	2.3	5.0	.....	19	2.6	3.4	4.0	.....
4	2.65	2.3	7.4	.....	20	2.6	4.0	4.3	.....
5	2.65	2.3	14.0	.....	21	2.6	5.5	3.9	.....
6	5.4	2.3	8.9	.....	22	2.6	7.0	3.6	.....
7	6.7	2.3	7.5	.....	23	2.6	7.6	3.4	.....
8	5.0	2.4	5.8	.....	24	2.6	6.0	3.2	.....
9	4.0	2.4	4.8	.....	25	2.6	4.9	3.1	.....
10	3.6	2.5	5.3	.....	26	2.6	4.9	3.1	.....
11	3.4	2.5	4.8	.....	27	2.6	6.0	3.0	.....
12	3.2	2.5	4.6	.....	28	2.6	9.0	3.0	.....
13	3.0	2.5	4.0	.....	29	2.5	.....	3.0	.....
14	2.9	2.7	3.8	.....	30	2.5	.....	3.0	.....
15	2.8	2.8	4.5	.....	31	2.4	.....	3.0	.....
16	2.8	3.0	4.2	.....					

Rating table for North River at Port Republic, Va., from August 5, 1895, to April 1, 1899.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.6	165	3.2	1,050	4.8	3,410	8.5	9,145
1.8	215	3.4	1,290	5.0	3,720	9.0	9,920
2.0	275	3.6	1,550	5.5	4,495	9.5	10,695
2.2	350	3.8	1,860	6.0	5,270	10.0	11,470
2.4	445	4.0	2,170	6.5	6,045	10.5	12,245
2.6	555	4.2	2,480	7.0	6,820	11.0	13,020
2.8	700	4.4	2,790	7.5	7,595		
3.0	865	4.6	3,100	8.0	8,370		

[a] This table is strictly applicable only for open-channel conditions. It is not well defined.

stimated monthly discharge of North River at Port Republic, Va.

[Drainage area, 804 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1895.					
	445	292	319	0.40	0.39
	2,635	245	346	.44	.49
	245	202	219	.27	.31
	275	202	239	.30	.33
	500	215	251	.31	.36
1896.					
	5,502	275	799	.99	1.14
	4,805	500	1,488	1.85	1.93
	7,130	445	1,653	2.05	2.37
	4,340	350	1,594	1.98	1.33
	4,960	395	824	1.02	1.18
	2,945	350	642	.80	.89
	7,595	472	1,085	1.35	1.56
	1,550	310	458	.57	.66
	23,870	177	1,224	1.52	1.70
	7,595	420	931	1.16	1.34
	5,270	420	1,088	1.35	1.51
	2,790	420	699	.87	1.00
1897.					
	420	372	388	.48	.55
	11,240	420	3,138	3.90	4.06
	2,015	625	1,250	1.55	1.79
	865	445	642	.80	.89
	13,790	445	2,212	2.75	3.17
	865	420	489	.61	.68
	1,420	330	463	.58	.67
	330	275	292	.36	.41
	275	215	234	.29	.32
	310	215	250	.31	.35
	555	215	256	.32	.36
	590	230	319	.39	.45
	13,790	215	829	1.03	13.70
1898.					
	700	275	491	.61	.70
	625	310	414	.51	.53
	2,480	310	581	.72	.80
	4,030	555	1,110	1.38	1.54
	7,207	445	1,430	1.78	2.05
	2,480	275	585	.73	.81
	3,720	275	822	1.02	1.18
	9,920	555	3,030	3.77	4.35
	662	445	520	.65	.72
	11,470	275	1,814	2.26	2.61
	865	330	507	.63	.70
	6,820	395	1,089	1.35	1.56
	11,470	275	1,032	1.28	17.55
1899.					
	6,355	445	1,126	1.40	1.61
	9,920	395	2,132	2.65	2.76
	17,670	865	3,452	4.29	4.95

[a] Discharge interpolated November 24–28, 1895.

MISCELLANEOUS DISCHARGE MEASUREMENTS IN NORTH RIVER BASIN.

The following miscellaneous measurements have been made in the basin of North River:

Miscellaneous discharge measurements in North River basin.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*
March 22	Middle River	At mouth near Mount Meridian, Va.	114	396	1.58	625
April 19	do	do		228	1.00	229
November 7	do	do	90	151	.61	92
March 22	North River	Above junction with Middle River near Mount Meridian, Va.				841
November 7	do	do				153

SOUTH FORK OF SHENANDOAH RIVER BASIN BELOW PORT REPUBLIC, VA.

GENERAL DESCRIPTION.

South Fork of Shenandoah River is formed at Port Republic, Rockingham County, Va., by the union of North and South rivers, and flows northeastward to Riverton, Va., where it unites with North Fork to form the main Shenandoah. Its length by river course is about 96 miles.

South Fork of the Shenandoah is to a certain extent navigable for small boats, and works have at various times been executed for improving it. The basin is traversed by the Norfolk and Western Railway, and nearly every part of it is accessible. Theoretically a large amount of power is available, but very little is utilized. The bed and banks are favorable for the construction of dams, but space for canals and buildings is in places small.

The river is subject to frequent and rapidly rising freshets. The stream flows alternately in pools of comparatively slack water and over ledges and shoals, forming rapids and falls, the pools being shorter and the ledges more numerous in the upper reaches than in the lower.

In August, 1899, a reconnaissance survey of South Fork of Shenandoah River between Port Republic and Riverton, Va., was made by F. H. Anschutz, under the direction of D. C. Humphreys, for the purpose of obtaining a profile of the river and a map showing the location of the mills, the unused falls, and the localities where water power might possibly be developed.

The results of the work are shown by the profile (Pl. III, p. 134). The distances along the profile and map are measured along the center line of the stream, the initial point being the forks of the river at Port Republic.

The developed and undeveloped power of the river at the time of the survey was briefly stated, as follows:

At Port Republic a combined sawmill and gristmill utilizes a fall of 10 feet in South River, which is obtained by a dam about a quarter of a mile above the mouth.

On North River, in the first 1,500 feet above the forks, there is a fall of 6 feet which was once used for power and which could easily be developed again.

At Shendun, 4 miles above Port Republic, on South River, an excellent power was partially developed during what is known as "boom times" in 1890. The fall is said to be about 20 feet.

Two miles downstream from the forks there is a gristmill utilizing about 6 feet fall, obtained by a brush dam and a long race.

At 6 miles there is a fall of 4.5 feet, but the banks are low.

At 7½ miles there is a small gristmill with a 3-foot timber dam.

Between the 7½-mile point and the next mill, at 11 miles, there is a total fall of 25 feet, but the river banks are much broken and generally are low.

At 11 miles there is a small gristmill using about 6 feet fall.

At 12½ miles there is a gristmill using 5½ feet fall.

At 17 miles, opposite Elkton, there is a combined gristmill and sawmill, with a 4-foot dam, using 6 feet fall.

In the neighborhood of Shenandoah the fall is rapid, but the banks are low.

At 31½ miles there is an old mill and a timber dam 4 feet high, the first course of timbers of which is missing.

At 32½ miles, Grove Hill, there is a gristmill and a good dam of timber and loose rocks, 4 feet high.

At 37½ miles, Kemple Falls, there is a fall of 15 feet in three-fourths of a mile. The bank on the left side is fairly good, but on the right side of the main group of channels the river spreads out over and runs through a large area of bowlders, and the bank for a considerable distance back is but little above the surface of the stream.

At 38 miles, Newport, there is a combined sawmill and gristmill that uses about 6 feet fall. The dam is about 4 feet high, loosely made of timber and stonework.

At 41 miles is Manks' mill, a gristmill with a dam 3½ feet high, rudely constructed of brush and loose stone. The fall below the mill is good and about 7 feet are utilized.

At 50 miles there is an old mill site, nothing being left except the foundation of the dam.

At 55 miles, Schuler, there is a gristmill, with a dam 3½ feet high.

At 66½ miles is Goode's mill, the dam for which is 3 feet high, of timber and planking backed by loose rock. The mill uses a fall of about 6 feet.

At 79½ miles is Hazard's mill, on the left bank of the stream, at a point where the river splits and runs around a large island. The dam is in the left branch and is substantially constructed of timber; it is 4½ feet high.

At 97½ miles is Blackmore's dam. It was a stoutly built dam of timber and dry masonry, but it is broken at each end and part of the upper course is missing at the middle. The mill is no longer standing.

At 101 miles, Riverton, are the Riverton mills. The dam is 6 feet high,[a] of timber and is well constructed.

[a] See description of station on North Fork of Shenandoah River near Riverton, Va., pp. 125–126.

ELK RUN AT ELKTON, VA.

Elk Run rises in the Blue Ridge in the eastern part of Rockingham County, Va., and flows northwestward into South Fork of Shenandoah River near Elkton.

The gaging station was established June 28, 1905, by N. C. Grover, in connection with the investigation of stream pollution in the Shenandoah Valley. It was discontinued July 16, 1906. It is located at the highway bridge 500 feet south of the railroad station at Elkton, Va.

The channel is straight for 100 feet above and 200 feet below the station. The current is sluggish at the gage. Both banks are low and overflow during high water. All the water passes beneath the bridge, except during extreme floods. The bed of the stream is composed of gravel and is permanent. The stream is highly polluted by waste from tanneries along its banks.

Discharge measurements were made at ordinary stages at a footbridge 1,000 feet downstream from the bridge to which the gage is fastened. During high water discharge measurements were made from the highway bridge.

A standard chain gage is fastened to a floor beam on the downstream side of the bridge, near the right end. The length of the chain from the end of the weight to the marker is 8.74 feet. The gage was read once each day by C. L. Gooden. Bench mark No. 2 is the underside of the coping at the southwest corner of the first railway-bridge pier on the right bank of the creek, marked with red paint "U. S. G. S. B. M." Its elevation is 11.96 feet above the datum of the gage.

Unsatisfactory conditions of flow prevail at this station. The discharge measurements plot very erratically, owing probably to changes at the controlling point below the station. It was necessary to obtain the discharge by an indirect method based on the assumption of a gradual change in channel conditions between successive measurements. The estimates can probably be considered accurate within only 20 per cent of the true flow. Ice conditions probably affect the flow somewhat.

Discharge measurements of Elk Run at Elkton, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
May 22		4.9	April 11	2.78	15.7
Do		4.0	June 14	2.57	6.5
June 28	2.80	17.4			
July 20	2.10	3.4			
December 28	2.78	11.0			

Daily gage height, in feet, of Elk Run at Elkton, Va.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
							2.7	2.6	2.6	2.5	2.7	2.7
							2.7	2.55	2.5	2.5	2.7	2.7
							2.6	2.55	2.5	2.5	2.7	2.7
							2.6	2.5	2.5	2.45	2.7	2.7
							2.6	2.5	2.6	2.45	2.7	2.7
							2.6	2.5	2.5	2.5	2.7	2.7
							2.6	2.5	2.4	2.5	2.7	2.7
							2.6	2.65	2.4	2.5	2.8	2.65
							2.5	2.6	2.4	2.6	2.7	2.65
							2.55	2.5	2.4	2.6	2.7	2.7
							2.55	2.7	2.45	3.2	2.7	2.7
							3.5	2.7	2.4	2.9	2.7	2.65
							3.1	3.2	2.45	2.7	2.7	2.65
							2.9	3.9	2.45	2.6	2.8	2.65
							2.7	3.0	2.45	2.6	2.7	2.6
							2.6	2.8	2.4	2.6	2.7	2.6
							2.6	2.7	2.4	2.7	2.7	2.6
							2.6	2.6	2.4	2.65	2.7	2.6
							2.55	2.65	2.4	2.65	2.7	2.7
							2.5	2.6	2.9	2.65	2.75	3.3
							2.55	2.6	2.6	2.7	2.7	3.5
							2.7	2.65	2.5	2.7	2.65	2.8
							2.5	2.6	2.5	2.7	2.65	2.7
							2.5	3.1	2.5	2.7	2.65	2.7
							2.5	3.2	2.5	2.8	2.65	2.8
							2.5	3.0	2.5	2.8	2.65	2.7
							2.5	3.0	2.5	2.7	2.65	2.8
						2.75	2.6	2.8	2.5	2.7	2.65	2.8
						2.8	2.6	2.7	2.5	2.7	2.65	3.0
						2.65	2.6	2.7	2.5	2.7	2.65	2.95
							2.6	2.6		2.7		2.9
1906.[a]												
	2.85	2.9	2.7	3.1	2.9	2.67	2.5					
	2.8	2.95	2.7	3.8	2.88	2.5	2.5					
	2.75	2.9	3.35	3.0	2.75	2.6	2.5					
	3.25	2.9	3.3	2.95	2.8	2.65	2.6					
	3.1	2.9	2.9	2.85	2.8	2.51	2.5					
	3.0	2.85	2.85	2.9	2.9	2.6	3.5					
	2.91	2.85	2.8	2.85	2.95	2.59	2.8					
	2.8	2.8	2.8	2.8	2.9	2.5	2.78					
	2.96	2.8	2.81	2.95	2.8	2.6	2.7					
	2.91	2.8	2.7	2.8	2.87	2.58	2.72					
	2.9	2.8	2.8	2.85	2.85	2.53	2.7					
	2.8	2.78	2.75	2.8	2.7	2.6	2.72					
	2.8	2.77	2.85	2.8	2.75	2.58	2.7					
	2.8	2.75	2.95	2.85	2.7	2.47	2.7					
	3.0	2.7	3.0	4.5	2.55	2.58	2.75					
	2.9	2.77	3.1	3.5	2.64	2.6						
	2.85	2.7	3.0	3.2	2.6	2.6						
	2.8	2.7	2.95	3.0	2.6	2.65						
	2.8	2.8	2.9	2.95	2.6	2.7						
	2.75	2.72	2.85	2.85	2.6	3.65						
	2.75	2.7	2.9	2.9	2.55	2.9						
	2.8	2.78	2.9	2.9	2.62	3.2						
	3.0	2.77	2.85	2.85	2.6	2.9						
	3.1	2.8	2.8	2.8	2.5	2.87						
	3.0	2.75	2.7	2.8	2.6	2.82						
	2.95	2.78	2.9	2.95	2.62	2.72						
	3.0	2.75	2.85	3.0	2.5	2.63						
	3.15	2.75	2.9	2.95	2.72	2.6						
	2.95		3.0	2.95	2.7	2.6						
	3.0		2.9	2.85	2.65	2.55						
	2.9		3.1		2.7							

[a] Slight ice conditions during the winter season.

Estimated monthly discharge of Elk Run at Elkton, Va.

[Drainage area, 15.8 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
July	57	7.0	11.9	0.753	0.868
August	85	7.0	14.1	.892	1.03
September	15	5.5	6.73	.426	.48
October	27	6.0	9.39	.594	.68
November	12	8.5	9.40	.595	.66
December	46	7.5	11.8	.747	.86
1906.					
January	29	10	15.8	1.00	1.15
February	18	11	13.5	.854	.89
March	42	11	19.3	1.22	1.41
April	132	15	27.0	1.71	1.91
May	20	6.5	11.5	.728	.84
June	54	5.5	9.9	.627	.70
July 1-15	44	6	10.7	.677	.38

HAWKSBILL CREEK NEAR LURAY, VA.

Hawksbill Creek rises in the Blue Ridge in the southeastern part of Page County, Va., and flows northward into South Fork of Shenandoah River about 4 miles north of Luray.

The gaging station was established June 27, 1905, by N. C. Grover, in connection with the investigation of stream pollution in the Shenandoah River valley. It was discontinued July 16, 1906. It is located a short distance above the mouth of Dry Run, 1½ miles north of Luray.

The channel is straight for 500 feet above and 200 feet below the station. The current is moderate above and swift below the station. Rapids below the gage prevent backwater influence from Dry Run, except in case of extreme floods. From well-defined marks the highest stage known was found to be 19.55 feet above the zero of the gage. This stage occurred October 13, 1893. The right bank is high, rocky, and wooded, and does not overflow. The left bank is low and subject to overflow during high water. The bed of the stream is composed of gravel, is free from vegetation, and is permanent. There is but one channel at all stages. The approximate depth of the water at the bridge is 2 to 3 feet.

Discharge measurements were made from the footbridge in front of the observer's house. The initial point for soundings is the edge of rock at the right end of the bridge.

A staff gage in two sections, the lower one inclined and the upper vertical, graduated to feet and tenths, is fastened to the left bank 100 feet above the footbridge. The gage was read once each day by J. S. Miller. Bench mark No. 2 is the top of the stone under the vertical post on the upstream side of door frame in the old dairy building, 200 feet from the left end of the footbridge. Its elevation *is 15.10 feet* above the zero of the gage.

timates at this station are within 5 per cent of the true flow for ıal conditions between gage heights 1.4 and 2.0 feet. Above and v these stages the probable error is 10 per cent. The flow was ably unaffected by ice conditions during the winter of 1905–6.

Discharge measurements of Hawksbill Creek near Luray, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
.....	1.44	35	April 12.....	1.86	75
.....	1.74	64	June 15[a].....	1.50	36
ber 28.....	1.81	72			

[a] Measurement made by wading below footbridge.

Daily gage height, in feet, of Hawksbill Creek near Luray, Va.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
.....						.....	1.6	1.45	1.4	1.35	1.4	1.4
.....						.....	1.6	1.4	1.4	1.35	1.4	1.4
.....						.....	1.6	1.4	1.4	1.4	1.4	1.65
.....						.....	1.55	1.4	1.35	1.35	1.4	1.6
.....						.....	1.55	1.4	1.3	1.35	1.4	1.5
.....						.....	1.55	1.4	1.3	1.35	1.45	1.45
.....						.....	1.55	1.4	1.3	35	1.45	1.45
.....						.....	1.55	1.4	1.3	1.35	1.4	1.45
.....						.....	1.5	1.4	1.3	1.35	1.4	1.45
.....						.....	1.5	1.4	1.4	1.35	1.4	1.45
.....						.....	1.5	1.4	1.4	1.45	1.4	1.45
.....						.....	1.5	1.4	1.4	1.45	1.4	1.45
.....						.....	1.5	1.4	1.35	1.4	1.4	1.45
.....						.....	1.5	1.4	1.3	1.4	1.4	1.45
.....						.....	1.45	1.35	1.3	1.4	1.4	1.45
.....						.....	1.4	1.35	1.3	1.35	1.4	1.45
.....						.....	1.4	1.35	1.35	1.35	1.4	1.4
.....						.....	1.4	1.45	1.5	1.35	1.4	1.4
.....						.....	1.4	1.45	1.35	1.35	1.4	1.5
.....						.....	1.4	1.45	1.35	1.35	1.4	1.5
.....						.....	1.4	1.45	1.35	1.35	1.4	2.9
.....						.....	1.4	1.45	1.35	1.35	1.4	2.75
.....						.....	1.45	1.45	1.35	1.35	1.4	2.65
.....						.....	1.45	1.75	1.4	1.4	1.35	2.5
.....						.....	1.45	1.5	1.4	1.5	1.35	2.35
.....						.....	1.4	1.65	1.4	1.6	1.35	2.2
.....						1.75	1.4	1.	1.4	1.5	1.35	2.0
.....						1.7	1.4	1.	1.35	1.45	1.4	1.85
.....						1.65	1.4	1.	1.35	1.45	1.45	1.75
.....						1.6	1.6	1.4	1.35	1.45	1.4	2.4
.....						.....	1.5	1.4	.....	4	.....	2.25

Daily gage height, in feet, of Hawksbill Creek near Luray, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	De.
1906.												
1	2.0	1.9	.55	2.3	1.9	1.6	1.6					
2	1.9	1.9	.55	2.2	1.85	1.6	1.55					
3	3.3	1.9	.8	2.1	1.85	1.55	1.55					
4	2.7	1.85	2.0	2.05	1.85	1.55	1.55					
5	2.45	1.85	.95	2.0	1.8	1.5	1.55					
6	2.25	1.75	1.85	1.95	1.75	1.5	1.5					
7	2.2	1.7	.85	1.95	1.75	1.5	1.5					
8	2.1	1.7	1.85	1.9	1.75	1.5	1.5					
9	2.0	1.7	1.8	1.9	1.75	1.5	1.5					
10	2.05	1.65	1.8	1.95	1.75	2.0	1.5					
11	2.0	1.65	1.75	1.9	1.75	1.8	1.8					
12	1.9	1.65	1.7	1.9	1.	1.6	1.6					
13	1.8	1.65	1.7	1.8	1.	1.55	1.55					
14	1.8	1.7	1.7	1.8	1.65	1.55	1.55					
15	1.8	1.65	1.75	[a]3.35	1.65	2.05	1.55					
16	1.8	1.6	1.8	3.05	1.65	1.95						
17	1.75	1.6	1.75	2.55	1.65	2.5						
18	1.75	1.6	1.75	2.35	1.6	1.8						
19	1.75	1.55	1.85	2.25	1.6	1.6						
20	1.75	1.55	1.9	2.2	1.6	1.6						
21	1.7	1.6	1.9	2.1	1.6	2.45						
22	1.65	1.55	1.9	2.0	1.55	1.75						
23	1.75	1.55	1.9	1.85	1.5	1.7						
24	1.75	1.5	1.9	1.85	1.5	1.7						
25	1.8	1.55	1.9	1.85	1.5	1.7						
26	1.8	1.55	1.9	2.1	1.5	1.8						
27	1.9	1.55	2.15	2.05	1.5	1.8						
28	1.9	1.55	2.4	2.0	1.6	1.75						
29	1.9		2.35	1.9	1.6	1.7						
30	1.9		2.3	1.9	1.55	1.65						
31	1.9		2.4		1.5							

[a] Gage height estimated Apr. 15, 1906.

Rating table for Hawksbill Creek near Luray, Va., from June 27, 1905, to July 15, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.30	24	1.90	83	2.50	196	3.00	326
1.40	30	2.00	98	2.60	220	3.10	355
1.50	37	2.10	115	2.70	245	3.20	384
1.60	46	2.20	133	2.80	271	3.30	414
1.70	57	2.30	152	2.90	298	3.40	445
1.80	69	2.40	173				

[a] This table is strictly applicable only for open-channel conditions. It is based on five discharge measurements made during 1905-6. It is fairly well defined between gage heights 1.4 feet and 2.0 feet

Estimated monthly discharge of Hawksbill Creek near Luray, Va.

[Drainage area, 52 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1905.					
30	63	46	54.5	1.05	0.156
	46	30	36.1	.694	.800
	63	27	32.6	.627	.723
	37	24	27.5	.529	.590
	46	27	30.0	.577	.665
	34	27	30.0	.577	.644
	298	30	81.7	1.57	1.81
1906.					
	414	52	100	1.92	2.21
	83	37	53.9	1.04	1.08
	173	42	85.2	1.64	1.89
	430	69	123	2.37	2.64
	83	37	53.6	1.03	1.19
	232	37	68.8	1.32	1.47
5	69	37	42.7	.821	.458

SOUTH FORK OF SHENANDOAH RIVER NEAR FRONT ROYAL, VA.

h Fork of Shenandoah River is formed at Port Republic, gham County, Va., by the union of North and South rivers, ws northeastward to Riverton, Va., where it unites with North) form the main Shenandoah. Its length by river course is)6 miles.

gaging station at Front Royal was established June 26, 1899, P. Davis, and was discontinued July 17, 1906. It is located mile above the bridge, which is near the Norfolk and Western y station.

channel is straight for 600 feet above and below the station, e current is sluggish. The railroad follows the right bank of)am, and the railroad embankment, a few feet back from the i overflowed at extreme flood stages only. The bed of the is composed of bed rock and is very uneven; in places the overlain by silt, and this is liable to shift.

iarge measurements were made from a cable, which has a span feet and is suspended over the branches of two large sycamore /ith its right end fastened to the tree and its left anchored in und. The initial point for soundings is on the main cable 0.5)m the tree on the left bank.

gage is a vertical timber spiked to a large sycamore tree on the nk, about 800 feet upstream from the cable. A high-water)ading from 14 to 26 feet, was established September 18, 1905. /ertical board spiked to the shore side of a large sycamore tree, t upstream from the regular gage. The gage was read twice ,y by Miss Brentie Johnson. The bench mark is a headless n the river side of an elm tree on the left bank, 8 feet down- from the gage. It is 1.5 feet above the ground and has an)n of 10.49 feet above the zero of the gage.

Estimates for this station are within 5 per cent of the true discharge for normal conditions of flow for gage heights below 9.0 feet. Above gage height 9.0 feet the probable error of the extension of the curve may be as much as 15 to 20 per cent. Estimates for the winter months are affected by ice conditions. All estimates published prior to 1905 have been revised.

A summary of the records furnishes the following results: Maximum discharge for twenty-four hours, 76,800 second-feet; minimum discharge for twenty-four hours, 305 second-feet; mean annual discharge for five years, 2,238 second-feet; mean annual rainfall for seven years, 37.45 inches.

Discharge measurements of South Fork of Shenandoah River near Front Royal, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1899.	*Feet.*	*Second-feet.*	1904.	*Feet.*	*Second-feet.*
September 1	4.40	616	June 11	4.79	1,1
1900.			June 30	4.55	9
February 14	5.75	1,955	September 27	3.50	
June 19	7.90	5,703	October 19	3.42	
September 8	4.00	536	1905.		
1901.			April 4	4.78	1,2
July 21	6.95	4,211	May 16	5.28	1,6
1902.			September 18	3.95	
August 15	4.20	527	October 27	3.84	
1903.			December 26	5.94	2,3
August 19	4.90	1,065	1906.		
			June 16	4.70	1,0

Daily gage height, in feet, of South Fork of Shenandoah River near Front Royal, Va.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899.												
1							4.3	4.4	4.4	4.45	5.5	4.4
2							4.3	4.35	4.35	4.4	8.05	4.4
3							4.2	4.2	4.3	4.3	6.7	4.3
4							4.2	4.25	4.2	4.3	5.85	4.3
5							4.1	4.25	4.5	4.3	5.8	4.2
6							4.2	4.2	4.3	4.3	5.65	4.2
7							4.2	4.3	4.2	4.3	5.35	4.2
8							4.25	4.65	4.15	4.35	5.2	4.2
9							4.55	4.3	4.25	4.4	5.05	4.3
10							4.7	4.5	4.75	4.4	4.85	4.3
11							4.3	4.45	4.65	4.4	4.8	4.3
12							4.2	4.3	4.55	4.4	4.7	4.4
13							4.15	4.2	4.45	4.3	4.7	6.9
14							4.2	4.2	4.4	4.3	4.6	6.2
15							4.15	4.2	4.3	4.3	4.6	5.7
16							4.25	4.3	4.3	4.2	4.55	5.4
17							4.15	4.35	4.3	4.2	4.5	5.2
18							4.15	4.25	4.2	4.2	4.5	5.1
19							4.15	4.3	4.2	4.2	4.5	5.0
20							4.1	4.25	4.55	4.2	4.5	4.9
21							4.1	4.2	5.8	4.1	4.5	4.8
22							4.1	4.1	5.3	4.15	4.4	4.7
23							4.15	4.1	4.85	4.2	4.4	4.7
24							4.1	4.0	4.6	4.2	4.5	4.6
25							4.1	3.9	5.0	4.2	4.5	4.5
26						4.4	4.05	4.0	4.6	4.2	4.55	5.1
27						4.3	4.1	4.0	4.55	4.2	4.5	5.0
28						4.25	4.2	4.3	4.6	4.2	4.4	5.0
29						4.35	4.3	5.15	4.5	4.2	4.4	5.0
30						4.3	4.8	5.05	4.5	4.2	4.4	5.0
31							4.25	4.6		4.2		5.0

y gage height, in feet, of South Fork of Shenandoah River near Front Royal, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1900.												
	5.55	4.95	6.4	5.9	5.3	4.95	4.8	4.6	4.1	4.3	4.5	5.3
	5.55	4.8	10.65	5.75	5.25	4.85	4.7	4.55	4.1	4.25	4.5	5.35
	5.6	5.0	8.8	5.7	5.15	4.8	4.6	4.45	4.1	4.25	4.4	5.15
	5.55	5.6	7.55	5.6	5.1	4.8	4.6	4.4	4.1	4.25	4.45	5.55
	5.5	5.2	6.9	5.5	5.0	4.8	4.6	4.4	4.1	4.4	4.55	5.8
	5.35	5.65	6.6	5.4	5.0	4.8	4.5	4.3	4.0	4.3	4.6	7.6
	5.1	5.4	6.35	5.4	5.0	4.7	4.5	4.3	4.0	4.4	4.5	6.75
	5.05	5.0	6.2	5.3	4.9	4.7	4.5	4.3	4.0	4.4	4.5	6.1
	4.95	5.0	6.1	5.2	4.8	4.7	4.4	4.2	4.0	4.3	4.5	5.95
	5.05	5.0	6.0	5.2	4.8	4.6	4.4	4.2	4.0	4.4	4.4	5.85
	4.85	5.0	5.9	5.2	4.8	4.6	4.4	4.2	4.0	4.45	4.45	5.6
	4.95	4.95	5.8	5.1	4.7	4.5	4.4	4.2	3.9	4.45	4.45	5.45
	5.0	5.1	5.7	5.1	4.7	4.4	4.3	4.2	3.9	4.4	4.4	5.15
	5.6	6.35	5.6	5.1	4.7	4.7	4.3	4.2	3.9	4.25	4.4	5.1
	5.65	7.2	5.6	5.1	4.7	5.7	4.3	4.1	4.3	4.25	4.4	5.0
	5.0	6.5	5.5	5.1	4.7	6.25	4.3	4.1	4.65	4.3	4.3	4.9
	4.8	6.2	5.5	5.0	4.6	7.25	4.3	4.1	4.95	4.3	4.3	4.85
	4.8	5.95	5.5	5.0	4.5	7.95	4.2	4.0	4.65	4.4	4.3	4.8
	5.0	5.7	5.65	5.0	4.7	7.65	4.2	4.0	4.15	4.4	4.3	4.75
	7.2	5.55	6.55	5.4	5.3	6.85	4.2	4.0	4.15	4.3	4.3	4.7
	10.7	5.45	9.55	5.75	5.75	6.2	4.55	4.1	4.15	4.25	4.3	4.6
	8.35	6.25	8.35	5.9	5.55	5.8	4.9	4.2	4.15	5.05	4.4	4.6
	7.15	8.9	7.5	6.55	5.35	5.3	4.85	4.25	4.1	6.25	4.85	4.6
	6.5	8.65	6.6	6.7	5.25	5.35	4.65	4.3	4.2	6.95	4.95	4.6
	6.15	7.35	6.55	6.25	5.2	5.2	4.85	4.3	4.3	6.75	5.65	4.6
	5.8	6.85	6.45	6.3	5.35	5.1	4.95	4.3	4.35	5.6	6.65	4.6
	5.6	6.55	6.3	5.75	5.05	5.1	5.0	4.25	4.15	6.35	8.45	4.5
	5.55	6.2	6.25	5.55	4.9	5.2	4.9	4.2	4.05	5.05	7.3	4.5
	5.55	.....	6.15	5.4	4.85	5.05	4.85	4.2	4.0	4.65	6.35	4.5
	5.5	.....	6.0	5.4	4.8	4.9	4.8	4.1	4.2	4.55	5.85	4.5
	5.2	.....	5.95	.....	5.45	.....	4.7	4.1	.....	4.5	.....	4.5
1901.												
	4.5	4.65	4.3	5.45	6.25	7.7	7.2	6.05	6.75	9.55	4.5	5.7
	4.5	4.6	4.25	5.6	6.1	7.3	7.05	5.95	6.6	9.35	4.5	5.55
	4.4	4.6	4.3	5.85	5.95	6.9	6.8	5.9	6.35	8.6	4.9	5.4
	4.4	4.9	4.3	9.8	5.8	6.75	6.4	6.05	6.1	7.45	4.8	5.35
	4.4	5.1	4.3	8.3	5.75	6.55	6.05	5.45	5.85	6.65	4.75	5.25
	4.4	4.9	4.3	8.2	5.6	6.45	6.2	6.65	5.65	5.8	4.65	5.15
	4.4	4.9	4.2	7.7	5.55	6.7	6.3	8.2	5.45	5.65	4.6	5.1
	4.4	4.5	4.25	7.25	5.5	7.5	6.2	7.8	5.9	5.45	4.5	5.2
	4.2	4.5	4.3	6.7	5.9	7.15	6.05	7.0	5.75	5.25	4.5	5.35
	4.25	4.9	4.35	6.45	7.4	6.85	5.95	6.45	5.55	5.05	4.5	5.4
	4.4	4.9	7.05	6.15	7.25	6.6	5.7	6.8	5.35	4.95	4.5	5.5
	5.3	4.8	10.25	5.85	7.0	6.15	5.45	6.65	5.2	4.8	4.5	5.55
	7.35	4.7	7.7	5.6	6.5	5.95	5.3	6.55	5.05	5.3	4.45	5.6
	7.15	4.5	6.7	5.65	6.2	5.85	11.5	6.45	4.9	5.05	4.4	5.7
	6.75	4.5	6.25	16.3	6.45	5.7	9.6	6.25	5.4	4.95	4.4	11.5
	6.3	4.5	5.85	11.0	6.45	7.15	9.3	6.15	5.25	4.9	4.4	14.95
	5.75	4.9	5.65	8.65	5.95	9.9	8.1	5.95	5.05	4.8	4.5	10.1
	5.45	4.85	5.5	7.95	5.8	8.7	7.5	5.9	4.95	4.75	4.4	8.05
	5.3	4.75	5.4	7.55	5.65	7.3	7.35	5.75	4.8	4.7	4.4	7.6
	5.3	4.6	5.25	7.25	5.6	6.85	7.0	6.55	4.75	4.9	4.4	7.25
	5.3	4.5	5.2	18.5	5.5	10.3	6.75	7.5	4.7	4.85	4.4	6.45
	5.3	4.3	5.7	15.8	8.25	8.65	6.55	8.05	4.9	4.8	4.4	5.85
	5.15	4.3	5.35	11.35	17.5	7.6	6.35	7.75	4.75	4.7	4.55	5.65
	5.0	4.4	5.4	8.9	10.5	6.75	6.25	7.45	4.7	4.7	5.7	5.45
	4.95	4.4	5.4	7.8	9.4	6.45	6.0	4.95	4.65	4.6	6.15	5.4
	4.85	4.35	5.5	7.35	11.5	6.25	5.8	5.5	4.6	4.6	6.0	5.35
	4.9	4.3	5.65	7.2	10.9	6.15	5.4	6.4	4.5	4.8	5.55	5.55
	4.8	4.3	5.75	6.95	9.5	6.1	6.85	6.45	5.15	4.7	5.3	6.55
	4.8	.....	5.95	6.65	8.9	6.0	6.7	6.25	6.9	4.6	4.95	10.0
	4.7	.....	5.85	6.35	8.5	7.35	6.6	5.95	8.7	4.6	4.75	18.0
	4.7	.....	5.5	.....	6.1	.....	6.35	5.8	.....	4.55	.....	13.5

Daily gage height, in feet, of South Fork of Shenandoah River near Front Royal, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1902.												
1	9.5	6.1	23.5	6.55	5.4	4.9	4.6	4.4	4.0	5.0	4.25	5.
2	9.15	5.25	13.0	6.45	5.35	4.8	4.55	4.4	4.0	4.3	4.25	6.
3	8.3	6.7	9.9	6.25	5.3	4.75	4.5	4.6	3.95	6.0	4.4	6.
4	7.7	6.05	9.5	6.15	6.5	4.7	4.45	4.6	3.9	5.1	4.3	7.
5	8.4	6.6	8.9	5.95	6.35	4.6	4.4	4.6	3.9	5.0	4.3	7.
6	8.15	5.9	8.4	7.4	6.15	4.55	4.5	4.5	3.8	4.3	4.3	7.
7	8.0	5.7	7.95	7.25	5.85	4.5	4.45	4.5	3.8	4.3	4.2	6.
8	7.75	6.9	7.5	7.7	5.65	4.9	4.4	4.4	4.0	4.25	4.2	6.
9	7.55	5.9	9.1	9.1	5.5	4.9	4.4	4.3	4.2	4.2	4.2	6.
10	7.3	5.7	10.5	10.5	5.35	4.85	4.3	4.4	4.1	4.1	4.2	6.
11	6.55	5.9	13.25	10.5	5.5	4.8	4.3	4.35	4.1	4.1	4.25	5.
12	6.0	6.1	11.85	9.6	5.45	4.8	4.2	4.3	4.65	4.9	4.35	5.
13	5.9	6.1	10.1	6.9	5.4	4.7	4.6	4.3	4.0	5.5	4.35	5.
14	5.8	5.75	8.5	6.75	5.4	4.6	4.6	4.2	4.0	5.65	4.25	5.
15	5.75	5.45	8.1	6.6	5.3	4.8	4.5	4.2	4.0	5.35	4.1	5.
16	5.65	5.5	8.8	6.45	5.3	4.8	4.5	4.15	4.0	5.0	4.1	6.
17	5.55	5.4	8.45	6.25	5.3	4.7	4.45	4.25	4.1	4.65	4.6	6.
18	5.5	5.35	8.2	6.15	5.4	4.65	4.4	4.3	4.1	4.45	4.5	8.
19	5.5	5.3	7.8	6.0	5.4	4.6	4.35	4.35	3.9	4.4	4.5	7.
20	5.45	5.25	7.35	6.2	5.4	4.55	4.5	4.35	3.85	4.4	4.45	6.
21	5.35	5.2	6.75	6.15	5.3	4.45	4.5	4.3	3.8	4.35	4.4	6.
22	6.3	7.45	6.45	6.0	5.25	4.8	4.4	4.2	3.8	4.3	4.35	6.
23	5.75	6.2	7.9	5.8	5.2	4.75	4.4	4.1	4.0	4.3	4.3	6.
24	5.3	7.35	7.9	5.7	5.1	4.7	4.3	4.2	4.1	4.3	4.35	6.
25	5.3	11.0	7.8	5.55	5.2	4.6	4.25	4.15	4.15	4.35	4.4	5.
26	5.25	15.0	7.7	5.5	5.1	4.5	4.2	4.1	4.2	4.35	4.5	6.
27	6.4	20.0	7.6	5.6	5.1	4.5	5.5	4.1	4.2	4.4	5.75	5.
28	7.3	14.5	7.45	5.55	5.0	4.4	5.35	4.0	4.2	4.5	6.25	5.
29	8.55	.....	6.55	5.45	4.9	4.7	5.05	4.0	6.0	4.35	5.7	5.
30	6.7	.....	6.7	5.4	4.8	4.7	4.75	4.0	5.55	4.3	5.2	5.
31	5.45	.....	6.65	.....	4.75	.....	4.55	4.0	.....	4.3	.....	5.
1903.												
1	5.25	7.05	12.25	9.15	5.8	7.4	8.55	4.9	7.6	4.6	4.4	4.
2	6.1	6.6	9.4	8.1	5.7	6.5	7.0	4.9	6.45	4.6	4.45	4.
3	9.3	6.4	7.9	7.6	5.7	5.95	6.75	4.9	5.65	4.5	4.5	4.
4	11.25	8.2	7.45	7.35	5.6	5.75	6.55	5.35	5.35	4.5	4.55	4.
5	8.75	7.65	7.1	7.25	5.45	5.4	6.15	5.5	5.2	4.5	4.55	4.
6	7.7	7.15	6.75	6.95	5.5	6.0	5.75	5.6	5.15	4.5	4.5	4.
7	7.15	6.95	6.55	6.8	5.4	7.95	6.25	5.15	5.05	4.4	4.45	4.
8	6.7	6.65	6.65	6.7	5.4	11.0	5.95	4.85	4.85	5.5	4.4	4.
9	6.5	6.45	6.85	6.65	5.35	10.15	5.75	4.75	4.75	5.5	4.4	4.
10	6.1	6.25	6.75	6.55	5.3	7.9	5.55	4.7	4.8	6.0	4.45	4.
11	5.8	6.05	6.7	6.45	5.3	7.85	5.35	4.85	4.75	4.5	4.5	4.
12	5.75	6.1	6.6	6.35	5.25	7.7	5.25	5.3	4.7	4.7	4.4	4.
13	5.7	6.3	6.5	6.25	5.2	7.7	5.5	5.1	4.7	4.6	4.4	4.
14	5.75	6.15	6.45	8.4	5.15	6.7	8.15	4.8	4.7	4.55	4.4	4.
15	5.75	6.1	6.25	10.55	5.1	6.65	7.6	4.75	4.6	4.5	4.4	4.
16	5.4	6.7	6.15	9.35	5.05	6.6	5.9	4.7	4.5	4.4	4.4	4.
17	5.4	7.6	6.0	8.4	5.1	6.5	5.6	4.75	4.4	4.4	4.4	4.
18	5.4	8.75	5.9	7.9	5.1	6.45	5.35	4.8	7.8	4.5	4.5	4.
19	5.3	7.7	5.85	7.45	5.0	6.4	5.25	4.7	7.5	4.6	4.5	4.
20	5.3	7.1	5.75	7.1	5.0	6.4	5.05	4.7	6.7	4.65	4.4	4.
21	5.75	6.65	5.7	6.9	5.0	6.4	5.0	4.6	6.55	4.55	4.3	4.
22	6.95	6.25	5.85	6.8	4.95	6.35	5.9	4.6	5.55	4.5	4.3	4.
23	7.25	6.15	7.4	6.65	4.9	6.3	5.6	4.5	5.4	4.5	4.3	4.
24	6.6	6.6	11.6	6.45	4.9	6.25	5.75	4.5	5.3	4.5	4.4	4.
25	6.25	6.8	9.65	6.25	5.0	5.95	5.7	4.5	5.2	4.5	4.4	4.
26	5.85	6.65	8.15	6.2	5.0	5.75	5.6	4.5	5.1	4.45	4.5	5.
27	5.95	6.7	7.65	6.15	5.1	6.35	5.45	4.4	4.95	4.5	4.5	5.
28	7.3	7.3	6.95	6.05	5.15	7.4	5.25	4.5	4.85	4.5	4.7	5.
29	9.75	.....	6.85	6.0	5.2	8.55	4.95	4.9	4.75	4.45	4.65	5
30	8.6	.....	7.0	5.9	5.5	8.45	4.75	5.3	4.6	4.4	4.7	5
31	7.6	.....	10.65	.....	5.95	.....	4.8	5.75	.....	4.4	.....	5

gage height, in feet, of South Fork of Shenandoah River near Front Royal, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.a												
.....	4.95	4.2	4.85	5.2	6.4	4.95	4.5	4.1	3.6	3.4	3.42	3.45
.....	4.75	4.1	4.85	5.05	5.85	5.05	4.4	4.05	3.6	3.4	3.4	3.4
.....	4.75	4.15	5.05	4.85	5.45	5.3	4.3	4.1	3.6	3.4	3.4	3.5
.....	5.05	4.25	4.95	4.7	5.15	6.2	4.2	4.3	3.6	3.4	3.4	3.5
.....	5.05	4.25	5.05	4.65	5.1	6.45	4.1	4.4	3.6	3.4	3.42	3.5
.....	4.8	4.0	5.0	4.6	5.0	6 5	4.1	4.5	3.65	3.4	3.4	3.45
.....	4.7	4.05	5.05	4.6	5.0	6.0	4.05	4.7	3.7	3.4	3.42	3.42
.....	4.6	4.85	7.3	4.6	5.0	5.4	4.0	4.45	3.7	3.4	3.45	3.45
.....	4.55	4.65	7.4	4.7	5.15	5.05	4.2	4.4	3.7	3.4	3.5	3.45
.....	4.45	4.85	6.7	5.25	5.7	4.95	5.5	4.75	3.7	3.4	3.42	3.52
.....	4.4	4.85	6.0	5.75	5.85	4.75	7.95	4.6	3.7	3.4	3.4	4.15
.....	4.5	4.7	5.75	5.7	5.65	4.7	7.45	4.5	3.7	3.45	3.4	4.4
.....	4.55	4.6	5.55	5.35	5.35	4.65	5.4	4.4	3.7	3.55	3.4	4.6
.....	4.55	4.5	5.2	5.15	5.25	4.55	4.75	4.2	3.65	3.45	3.55	4.8
.....	4.4	4.4	5.1	4.95	4.9	4.5	4.55	4.15	4.15	3.4	3.5	3.95
.....	4.25	4.4	5.0	4.85	4.9	4.4	4.4	4.1	3.95	3.4	3.52	4.1
.....	4.25	4.35	4.9	4.8	4.9	4.6	4.35	4.0	3.7	3.4	3.5	4.1
.....	4.3	4.4	4.9	4.65	5.3	4.65	4.3	4.0	3.6	3.4	3.45	4.2
.....	4.4	4.6	4.9	4.55	5.7	4.4	4.35	3.9	3.6	3.4	3.45	3.9
.....	4.35	4.75	4.7	4.5	7.6	4.55	4.25	3.8	3.6	3.45	3.4	3.9
.....	4.35	4.85	4.7	4.5	6.75	5.0	4.1	3.8	3.5	3.55	3.42	3.7
.....	4.9	5.4	4.7	4.4	5.9	5.15	4.1	3.75	3.5	3.5	3.4	3.7
.....	6.75	6.9	4.95	4.4	5.45	5.05	4.0	3.65	3.5	3.45	3.42	3.88
.....	8.15	7.9	4.95	4.3	5.25	4.75	4.3	3.6	3.5	3.4	3.42	3.95
.....	b 5.75	b 7.7	4.95	4.4	5.1	4.4	4.4	3.6	3.5	3.4	3.42	3.9
.....	5.05	7.15	5.05	4.45	5.0	4.3	4.3	3.55	3.5	3.4	3.4	3.8
.....	4.8	6.35	5.1	5.5	4.95	4.35	4.2	3.5	3.4	3.42	3.4	3.95
.....	4.65	5.75	5.1	6.25	4.9	4.4	4.35	3.5	3.4	3.4	3.4	3.9
.....	4.45	5.2	5.0	6.8	4.9	4.7	4.15	3.5	3.4	3.4	3.4	4.5
.....	4.35	.....	5.25	6.65	4.8	4.5	4.2	3.55	3.4	3.4	3.4	4.2
.....	4.25	.....	5.3	.....	4.8	.....	4.2	3.6	.....	3.4	.....	4.0
1905.c												
.....	3.7	4.15	.....	5.4	4.3	4.35	4.85	4.85	4.3	3.7	3.82	3.7
.....	3.85	4.05	.....	5.4	4.2	4.25	4.7	4.7	4.38	3.7	3.7	3.8
.....	3.95	4.0	.....	5.28	4.2	4.15	4.55	4.6	4.85	3.7	3.8	3.8
.....	4.0	4.15	.....	5.2	4.0	4.3	4.5	4.5	4.65	3.6	3.78	3.75
.....	4.0	4.35	6.15	4.75	4.2	4.25	6.25	4.4	4.5	3.6	3.75	3.8
.....	4.0	4.25	5.85	5.15	4.15	4.2	5.7	4.4	4.4	3.6	3.8	3.82
.....	4.6	4.2	5.4	5.3	4.2	4.1	5.35	4.35	4.35	3.55	3.75	3.88
.....	5.15	4.3	5.05	5.15	4.1	4.1	5.05	4.25	4.3	3.6	3.7	4.25
.....	5.2	4.3	5.5	5.1	4.05	4.0	4.95	4.2	4.15	3.6	3.72	4.18
.....	4.6	4.5	6.65	5.1	4.0	4.0	4.8	4.1	4.0	3.6	3.72	4.05
.....	4.45	4.45	8.25	5.0	4.05	4.0	4.65	4.1	3.9	3.6	3.7	4.0
.....	4.85	4.4	7.4	4.8	4.15	4.0	5.15	4.0	3.88	3.65	3.8	4.12
.....	4.85	4.35	6.9	4.9	4.0	4.0	6.2	4.25	3.8	3.6	3.72	4.05
.....	5.1	4.4	6.52	4.8	5.45	3.9	7.45	4.4	3.9	3.7	3.7	3.95
.....	5.55	4.45	6.15	4.8	5.2	3.9	6.8	5.25	4.0	3.72	3.6	4.05
.....	5.2	4.35	6.0	4.7	5.28	3.8	7.6	6.2	3.95	3.8	3.65	4.15
.....	5.05	4.35	5.85	4.7	5.55	3.8	6.45	6.28	3.9	3.7	3.58	4.15
.....	4.9	4.4	5.8	4.6	5.55	3.8	5.7	5.65	3.9	3.7	3.65	4.25
.....	4.9	4.3	5.8	4.5	5.2	3.8	5.25	5.1	3.9	3.75	3.7	4.12
.....	4.45	4.3	5.75	4.4	4.45	4.2	5.0	4.78	3.9	3.75	3.7	4.0
.....	4.32	4.4	5.95	4.35	4.65	5.25	4.85	4.45	3.9	3.72	3.75	5.5
.....	4.22	4.4	7.0	4.3	4.45	4.95	4.6	4.3	3.8	3.72	3.68	8.32
.....	4.28	4.75	7.6	4.3	4.4	5.05	5.8	4.25	3.82	3.6	3.68	8.0
.....	4.1	4.95	6.9	4.3	4.35	6.2	6.9	4.2	3.82	3.5	3.62	6.75
.....	3.95	5.7	6.75	4.42	4.3	9.35	6.55	4.15	3.75	3.6	3.6	6.4
.....	4.15	6.45	5.55	4.4	4.25	7.3	6.35	4.1	3.7	3.65	3.65	5.95
.....	4.15	8.0	6.35	4.5	4.2	6.1	6.2	4.1	3.7	3.78	3.7	5.55
.....	4.1	.....	6.25	4.45	4.3	5.65	6.05	4.3	3.78	3.82	3.7	5.25
.....	4.3	.....	5.95	4.3	4.15	5.25	5.5	4.4	3.8	3.8	3.65	5.25
.....	4.25	.....	5.65	4.3	4.55	4.9	5.15	4.35	3.68	3.8	3.62	5.45
.....	4.05	.....	5.55	.....	4.55	.....	5.0	4.3	.....	3.82	.....	5.85

e conditions during January (ice about 8 inches thick) and December (ice about 3 inches thick),

ge heights January 25 to February 25, 1904, approximate. Gage not in correct position.
e conditions during January and February, 1905

Daily gage height, in feet, of South Fork of Shenandoah River near Front Royal, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.												
1	5.65	5.43	4.2	7.05	5.22	4.7	5.45					
2	5.45	5.3	4.17	6.8	5.1	4.62	5.28					
3	5.25	5.2	4.23	6.45	5.0	4.5	5.25					
4	6.13	5.1	5.05	6.25	4.95	4.42	5.25					
5	8.47	4.85	7.02	5.85	4.9	4.38	4.9					
6	7.22	4.82	6.33	5.68	4.85	4.3	4.45					
7	6.4	4.9	5.8	5.52	4.88	4.22	4.65					
8	6.0	4.73	5.47	5.4	5.0	4.2	4.62					
9	5.65	4.65	5.15	5.32	5.1	4.18	4.4					
10	5.38	4.5	5.15	5.3	5.05	4.1	4.28					
11	5.17	4.52	5.05	5.4	5.0	4.1	4.3					
12	5.0	4.45	4.9	5.35	4.9	4.15	4.38					
13	5.0	4.4	4.83	5.28	4.8	4.22	5.32					
14	5.0	4.4	4.7	5.2	4.78	4.2	4.65					
15	5.05	4.43	4.8	6.35	4.6	4.4	4.4					
16	5.3	4.32	5.25	7.75	4.62	4.65	4.25					
17	5.3	4.4	5.95	6.8	4.52	5.45						
18	5.3	4.33	5.77	6.38	4.55	5.75						
19	5.2	4.3	5.8	6.08	4.45	5.35						
20	5.12	4.3	5.75	5.8	4.4	5.35						
21	5.0	4.3	5.8	5.55	4.35	6.2						
22	4.9	4.25	6.1	5.45	4.3	6.9						
23	4.93	4.22	5.9	5.35	4.28	6.05						
24	6.8	4.28	5.8	5.25	4.2	5.5						
25	6.85	4.25	5.6	5.05	4.2	5.35						
26	6.22	4.25	5.58	5.1	4.2	5.28						
27	5.75	4.12	5.77	5.35	4.22	5.72						
28	5.63	4.25	6.75	5.45	4.3	6.15						
29	5.6		7.35	5.4	4.65	5.5						
30	5.55		7.1	5.3	4.4	5.35						
31	5.55		6.9		4.72							

Rating tables for South Fork of Shenandoah River near Front Royal, Va.

JUNE 26, 1899, TO DECEMBER 31, 1903.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.80	305	5.10	1,220	6.40	2,990	11.00	13,610
3.90	350	5.20	1,330	6.50	3,150	12.00	16,590
4.00	400	5.30	1,440	6.60	3,320	13.00	20,000
4.10	455	5.40	1,560	6.70	3,490	14.00	24,000
4.20	515	5.50	1,680	6.80	3,660	15.00	28,700
4.30	580	5.60	1,810	7.00	4,010	16.00	33,300
4.40	650	5.70	1,940	7.20	4,370	17.00	38,300
4.50	720	5.80	2,080	7.40	4,750	18.00	43,500
4.60	795	5.90	2,220	7.60	5,150	19.00	48,900
4.70	870	6.00	2,370	7.80	5,570	20.00	54,700
4.80	950	6.10	2,520	8.00	6,000	22.00	66,900
4.90	1,030	6.20	2,670	9.00	8,300	24.00	80,200
5.00	1,120	6.30	2,830	10.00	10,910		

[a] This table is strictly applicable only for open-channel conditions. It is based on five discharge measurements made during 1899–1903. It is well defined between gage heights 4.2 feet and 6.0 feet. Above gage height 8.0 feet estimates are based on a discharge curve which is the product of a well-defined area curve and an approximate extension of the velocity curve. The discharge curves for the periods 1899–1905, inclusive, are the same above gage height 10.6 feet.

ıg tables for South Fork of Shenandoah River near Front Royal, Va.—Continued.

JANUARY 1, 1904, TO JULY 16, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.40	320	4.50	890	5.60	2,070	6.70	3,770
3.50	350	4.60	970	5.70	2,210	6.80	3,940
3.60	385	4.70	1,060	5.80	2,350	6.90	4,120
3.70	425	4.80	1,150	5.90	2,490	7.00	4,300
3.80	465	4.90	1,250	6.00	2,640	7.20	4,680
3.90	510	5.00	1,350	6.10	2,790	7.40	5,080
4.00	560	5.10	1,460	6.20	2,940	7.60	5,480
4.10	610	5.20	1,570	6.30	3,100	7.80	5,900
4.20	670	5.30	1,690	6.40	3,260	8.00	6,320
4.30	740	5.40	1,810	6.50	3,430	9.00	8,550
4.40	810	5.50	1,940	6.60	3,600	10.00	10,980

ıis table is strictly applicable only for open-channel conditions. It is based on 9 discharge meas-ents made during 1904 to 1906. It is well defined between gage heights 3.4 feet and 5.3 feet. Above height 8.0 feet estimates are based upon a discharge curve which is the product of a well defined :urve and an approximate extension of the velocity curve. Above gage height 10.6 feet both rat-ıbles are the same.

imated monthly discharge of South Fork of Shenandoah River near Front Royal, Va.

[Drainage area, 1,570 square miles.[a]]

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1899.								
ary							2.52	
uary							4.95	
h							5.12	
							1.16	
							4.95	
26–30	650	547	594	.378	.070		[b]2.09	
	950	428	538	.343	.395	16	2.51	2.11
ıst	1,275	350	599	.382	.440	11	3.94	3.50
ımber	2,080	485	759	.484	.540	14	3.78	3.24
ber	685	455	559	.356	.410	18	2.34	1.93
mber	6,110	650	1,236	.788	.879	109	.81	— .07
mber	3,920	515	1,121	.714	.823	61	1.34	.52
The year							35.51	
1900.								
ary	12,800	950	2,265	1.44	1.66	65	2.57	.97
uary	8,060	950	2,492	1.59	1.66	45	3.73	2.01
h	12,680	1,680	3,551	2.26	2.61	70	3.72	1.14
l	3,490	1,120	1,755	1.12	1.25	66	1.89	.67
	2,010	720	1,160	.739	.852	35	2.42	1.57
	5,890	650	1,708	1.09	1.22	20	5.98	4.76
	1,120	515	776	.495	.571	15	3.76	3.19
ıst	795	400	538	.343	.395	21	1.93	1.53
ember	1,070	350	499	.318	.355	11	3.14	2.78
ber	3,920	547	1,042	.664	.765	24	3.19	2.43
ember	7,005	580	1,285	.819	.914	31	2.94	2.03
mber	5,150	720	1,417	.903	1.04	57	1.83	.79
The year	12,800	350	1,540	.982	13.29	36	37.10	23.81

Drainage area of 1,570 square miles used to obtain the run-off for 1906, and 1,569 used for all other rs.

[b] Precipitation for complete month, June, 1899.

Estimated monthly discharge of South Fork of Shenandoah River near Front Royal, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1901.								
January	4,055	515	1,366	.871	1.00	43	2.31	1.31
February	1,220	580	818	.521	.542	164	.33	−.21
March	11,580	515	1,975	1.26	1.45	38	3.80	2.35
April	46,200	1,810	8,374	5.34	5.96	95	6.24	.28
May	40,900	1,080	5,768	3.68	4.24	73	5.82	1.58
June	11,720	1,940	4,302	2.74	3.06	41	7.54	4.48
July	15,070	1,440	3,912	2.49	2.87	65	4.38	1.51
August	6,440	1,075	3,204	2.04	2.35	40	5.92	3.57
September	7,580	720	1,825	1.16	1.29	34	3.78	2.49
October	9,730	758	2,020	1.29	1.49	216	.69	−.80
November	2,595	650	966	.616	.687	34	2.01	1.32
December	43,500	1,220	5,984	3.81	4.39	72	6.12	1.73
The year	46,200	515	3,319	2.11	29.33	60	48.94	19.61
1902.								
January	9,600	1,385	3,730	2.38	2.74	102	2.69	−.05
February	54,700	1,330	6,439	4.10	4.27	96	4.46	.19
March	76,800	3,070	9,871	6.29	7.25	201	3.61	−3.64
April	12,260	1,560	3,826	2.44	2.72	122	2.23	−.49
May	3,150	910	1,579	1.01	1.16	44	2.64	1.48
June	1,030	650	861	.549	.612	21	2.93	2.32
July	1,680	515	754	.481	.554	25	2.17	1.62
August	795	400	571	.364	.420	19	2.22	1.80
September	2,370	305	531	.338	.377	15	2.59	2.21
October	2,370	455	848	.540	.623	17	3.65	3.03
November	2,750	455	784	.500	.558	17	3.21	2.65
December	6,220	1,440	3,040	1.94	2.24	66	3.38	1.14
The year	76,800	305	2,736	1.74	23.52	66	35.78	12.26
1903.								
January	14,320	1,385	3,850	2.46	2.84	70	4.08	1.24
February	7,700	2,445	3,768	2.40	2.50	72	3.49	.99
March	17,300	1,940	5,043	3.21	3.70	89	4.15	.45
April	12,400	2,220	4,404	2.86	3.19	88	3.62	.43
May	2,295	1,030	1,417	.903	1.04	39	2.69	1.65
June	13,610	1,560	4,308	2.74	3.06	40	7.63	4.57
July	7,225	910	2,338	1.49	1.72	56	3.06	1.34
August	2,010	650	1,046	.667	.769	22	3.53	2.76
September	5,570	650	1,738	1.11	1.24	51	2.42	1.18
October	2,370	650	842	.537	.619	26	2.39	1.77
November	870	580	691	.440	.491	60	.82	.33
December	1,680	580	853	.544	.627	66	.96	.33
The year	17,390	580	2,533	1.61	21.80	56	38.84	17.04
1904.								
January[a b]	6,650	705	1,293	.824	.950	53	1.80	.85
February[b]	6,110	560	1,649	1.05	1.13	90	1.26	.13
March	5,080	1,060	1,746	1.11	1.28	62	2.08	.80
April	3,940	740	1,486	.947	1.06	40	2.64	1.58
May	5,480	1,150	1,875	1.20	1.38	40	3.43	2.05
June	3,430	740	1,375	.876	.977	18	5.57	4.59
July	6,215	560	1,117	.712	.821	16	5.04	4.22
August	1,105	350	613	.391	.451	18	2.53	2.08
September	640	320	395	.252	.281	14	1.95	1.67
October	368	320	326	.208	.240	20	1.20	.96
November	368	320	329	.210	.234	24	.95	.72
December[a]	1,150	320	530	.338	.390	16	2.46	2.07
The year	6,650	320	1,061	.676	9.19	30	30.91	21.72

[a] Ice conditions during January and December, 1904; no correction made in estimates.
[b] Estimates January 25 to February 25, 1904, approximate.

monthly discharge of South Fork of Shenandoah River near Front Royal, Va.—Continued.

h.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
.....	2,005	425	917	.584	.673	24	2.79	2.12
-27 [a]	6,320	560	1,140	.726	.729	.....	[b] 2.11	.....
.....	6,870	1,405	3,104	1.98	1.99	.....	[b] 2.25	.....
.....	1,810	740	1,143	.728	.812	39	2.08	1.27
.....	2,005	560	920	.586	.676	20	3.45	2.77
.....	9,380	465	1,372	.874	.975	23	4.30	3.32
.....	5,480	890	2,236	1.42	1.64	26	6.23	4.59
.....	3,068	560	1,014	.646	.745	25	2.90	2.16
.....	1,200	417	595	.379	.423	25	1.68	1.26
.....	474	350	417	.266	.307	12	2.65	2.34
.....	474	378	425	.271	.302	36	.83	.53
.....	7,024	425	1,476	.941	1.08	28	3.81	2.73
ear....	.....	.....	.....	.....	.....	.....	35.08	.....

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1906.					
.....	7,354	1,250	2,283	1.45	1.67
.....	1,849	622	957	.610	.635
.....	4,980	652	2,233	1.42	1.64
.....	5,795	1,405	2,393	1.52	1.70
.....	1,594	670	1,049	.668	.770
.....	4,120	610	1,464	.932	1.04
.....	1,875	705	1,139	.725	.431

[a] conditions during January and February, 1905; no correction made in estimates.
[b] ecipitation for complete month, February and March, 1905.

NEOUS DISCHARGE MEASUREMENTS IN SOUTH FORK OF SHENANDOAH RIVER BASIN BELOW PORT REPUBLIC.

ollowing miscellaneous discharge measurements were made in n of South Fork of Shenandoah River below Port Republic:

ous discharge measurements in South Fork of Shenandoah River basin below Port Republic.

	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Square feet.*	*Feet per sec.*	*Second-feet.*
....	South Fork of Shenandoah River.	At Southern Rwy. bridge, 400 feet above junction of North and South Forks, near Riverton, Va.	.....	304	2.60	791
....	.....do.....	.....do.....	.....	252	2.27	572
....	.....do.....	Near Elkton, Va.....	.....	464	.84	389
....	Elk Run.....	.....do.....	11	8.4	.65	5.5
....	Naked Creek.....	Near Verbena, Va., ¼ mile above mouth.....	.....	.....	.....	[a] 25
....	Hawksbill Creek.....	Near Luray, Va.....	31	66	1.08	[b] 71
....	Flint Run.....	Near mouth, 5 miles above Front Royal, Va.	8	5	.64	[c] 3.2
....	Gooneys Creek.....	100 yards above mouth, under Norfolk and Western Rwy. bridge, 5 miles above Front Royal, Va.	6	5	.46	[d] 2.3

[a] 1 second-feet in tail race below mill.
[b] probably increased by rains of preceding week.
[c] Flint Run fed by large springs.
[d] Flow stated to be exceptionally low.

NORTH FORK OF SHENANDOAH RIVER BASIN.

PASSAGE CREEK AT BUCKTON, VA.

Passage Creek rises on Massanutten Mountain, in the western part of Page County, Va., flows northeastward, and joins North Fork of Shenandoah River about 5 miles above Riverton, Va.

The gaging station was established October 26, 1905, by Robert Follansbee and was discontinued July 16, 1906. It is located about 700 feet above the mouth of the creek, at the trestle of the Southern Railway at Buckton, which is a siding 1 mile east of Waterlick, Va.

The channel is straight for 200 feet above and 100 feet below the station. The current is moderate at the measuring section, but from a point 100 feet below the section to the mouth of the creek the velocity is rapid, the fall in that distance being from 6 to 8 feet. The banks above the bridge are fairly high, wooded, and not liable to overflow. Below the bridge they are low and liable to overflow during very high water, the flood plain being several hundred feet wide at such times. The channel between abutments is broken by seven trestle bents, and there are from three to eight channels, according to the stage of the river.

Discharge measurements at ordinary and low stages were made from the railway trestle or by wading a short distance above at a point where conditions are better. High-water measurements can be made from the highway bridge 2 miles upstream. This latter is not a good section at ordinary stages, as the current is too sluggish.

A staff gage, which is read once each day and oftener in floods by Nehemiah Messick, is nailed vertically to the third trestle bent from the left abutment.

The bench mark is the head of a nail 4 feet above ground, driven horizontally in a blaze on a tree situated 15 feet downstream from the lower end of the wing wall on the right bank; elevation, 5.41 feet above gage datum.

No estimates of flow have been made for this station, as the number of measurements is insufficient.

Discharge measurements of Passage Creek at Buckton, Va.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*	1906.	*Feet.*	*Second-feet.*
October 26	1.23	40	April 13	1.40	91
December 27	1.25	50	June 16	1.72	132

Daily gage height, in feet, of Passage Creek at Buckton, Va.

Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.
		1905.				1905.				1905.	
1		0.95	0.9	12		0.85	0.9	23		0.9	2.35
2		.9	.9	13		.9	.95	24		.85	2.0
3		.95	.95	14		.85	.9	25		.9	1.95
4		.9	1.4	15		.9	.95				
5		.95	1.2					26	1.2	.9	1.45
				16		.95	1.15	27	1.15	.85	1.4
6		.95	1.2	17		.85	a1.1	28	1.15	.9	1.25
7		.9	1.1	18		.9	a1.15	29	.9	.85	2.2
8		.95	1.15	19		.85	a1.1	30	.95	.95	1.8
9		.9	.95	20		.95	1.15	31	.95		1.4
10		.95	.95								
				21		.9	3.15				
11		.95	.95	22		.9	3.1				

y.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5,b												
1	1.4	1.2	1.1	2.6	1.3	.85	1.3					
2	1.35	1.25	1.0	2.2	1.3	.95	1.2					
3	1.3	1.3	1.1	1.9	1.3	.9	1.2					
4	3.4	1.3	3.1	1.8	1.25	.85	1.2					
5	2.0	1.3	2.2	1.7	1.25	.9	1.1					
6	1.8	1.4	1.6	1.6	1.25	1.1	1.0					
7	1.5	1.4	1.5	1.6	1.25	1.0	.9					
8	1.5	1.6	1.5	1.5	1.3	.9	.9					
9	1.5	1.7	1.5	1.3	1.25	.85	.85					
10	1.55	1.6	1.4	1.9	1.2	.85	.85					
11	1.55	1.5	1.3	1.6	1.2	.85	.85					
12	1.5	1.5	1.3	1.5	1.2	1.1	.8					
13	1.4	1.2	1.3	1.4	1.2	1.0	1.0					
14	1.4	1.1	1.3	1.4	1.2	.9	.85					
15	1.5	1.1	1.4	2.5	1.1	.9	.85					
16	1.45	1.2	1.4	2.4	1.1	1.6						
17	1.4	1.15	1.35	2.0	1.0	2.55						
18	1.3	1.15	1.4	1.85	1.0	3.2						
19	1.3	1.1	1.6	1.7	1.0	2.2						
20	1.3	1.1	1.5	1.6	1.0	2.1						
21	1.2	1.0	1.6	1.55	1.0	2.4						
22	1.2	1.0	1.8	1.5	.95	2.52						
23	1.2	1.0	2.2	1.4	.9	2.1						
24	1.25	1.0	2.1	1.4	.9	1.95						
25	1.2	1.0	2.1	1.4	.8	1.9						
26	1.2	1.0	2.1	1.4	.75	1.7						
27	1.2	1.0	2.6	1.65	.8	2.6						
28	1.25	1.1	3.4	1.5	.95	1.7						
29	1.2		3.4	1.4	1.0	1.6						
30	1.2		3.3	1.35	.9	1.4						
31	1.2		2.6		.85							

k frozen December 17–19, 1905. b Ice conditions February 4–13, 1906.

NORTH FORK OF SHENANDOAH RIVER NEAR RIVERTON, VA.

Fork of Shenandoah River rises in the northern part of Rock-ounty, Va., and flows in a very tortuous southeastward and ward course to Riverton, Va., where it unites with South form the main Shenandoah. Its drainage area is 1,040 iles.

w of this stream is rather variable, although the discharge of ts tributaries, especially in the upper part of the valley, is

The mills on North Fork are small, and the dams are gen-vood or brush.

Daily gage height, in feet, of North Fork of Shenandoah River near Riverton, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1900.[a] [b]												
1	4.0	5.0	5.05	4.7	4.25	3.8	3.9	3.72	3.6	3.8	3.7	4.8
2	4.0	5.0	7.85	4.58	4.17	3.8	3.9	3.65	3.6	3.8	3.72	4.8
3	4.0	5.0	6.55	4.52	4.15	3.8	3.85	3.6	3.62	3.75	3.7	4.6
4	4.0	5.0	5.4	4.48	4.1	3.9	3.78	3.55	3.62	3.7	3.75	4.6
5	4.0	4.9	5.1	4.4	4.05	3.88	3.72	3.52	3.58	3.7	3.7	6.1
6	4.0	4.5	4.88	4.32	4.05	3.82	3.72	3.5	3.6	3.7	3.7	5.7
7	4.0	4.38	4.82	4.28	4.0	3.8	3.7	3.5	3.6	3.78	3.7	5.5
8	4.0	4.1	4.75	4.25	3.98	3.8	3.7	3.55	6.58	3.8	3.7	4.7
9	4.0	4.0	4.68	4.2	3.95	3.8	3.68	3.58	3.6	3.7	3.65	4.6
10	4.0	3.95	4.6	4.15	3.92	3.8	3.68	3.6	3.6	3.7	3.62	4.6
11	4.0	4.0	4.5	4.15	3.9	3.75	3.62	3.6	3.6	3.68	3.7	4.5
12	4.0	3.98	4.42	4.15	3.9	3.72	3.62	3.58	3.6	3.65	3.6	4.9
13	4.0	4.12	4.38	4.15	3.9	3.7	3.62	3.5	3.58	3.7	3.6	4.8
14	3.98	5.1	4.35	4.15	3.9	3.72	3.65	3.5	3.6	3.7	3.68	4.8
15	3.92	5.2	4.35	4.1	3.9	3.75	3.62	3.5	3.6	3.7	3.65	4.9
16	3.9	4.87	4.35	4.1	3.82	3.78	3.6	3.55	3.7	3.7	3.6	4.8
17	3.8	4.62	4.3	4.1	3.8	4.45	3.68	3.6	3.68	3.78	3.6	4.6
18	3.8	4.42	4.25	4.1	3.8	5.75	3.62	3.6	3.65	3.8	3.62	4.9
19	3.92	4.35	4.5	4.2	3.8	5.75	3.6	3.55	3.68	3.75	3.62	4.9
20	4.92	4.35	6.95	4.55	3.8	4.98	3.6	3.55	3.6	3.7	3.65	4.8
21	7.3	4.25	8.2	4.6	3.8	4.62	3.62	3.5	3.6	3.7	3.7	4.7
22	5.65	4.75	6.7	4.6	3.8	4.3	3.7	3.62	3.58	3.7	3.62	4.6
23	4.9	6.98	5.9	5.22	3.8	4.2	3.82	3.6	3.58	3.7	3.6	4.8
24	4.55	6.3	5.42	5.4	3.8	4.15	5.28	3.6	3.6	3.75	3.68	4.8
25	4.25	5.63	5.18	5.1	3.8	4.08	4.32	3.6	3.6	3.78	3.7	4.7
26	4.02	5.15	5.0	4.75	3.8	4.0	4.22	3.6	3.6	3.85	4.65	4.8
27	4.0	4.9	5.0	4.62	3.8	3.92	4.0	3.55	3.6	3.9	7.0	4.8
28	4.0	4.8	4.9	4.5	3.8	3.9	3.92	3.6	3.62	3.8	5.25	4.8
29	4.5	.....	4.9	4.42	3.8	3.9	3.82	3.62	3.72	3.75	5.35	4.8
30	5.0	.....	4.85	4.32	3.8	3.9	4.08	3.6	3.95	3.72	4.45	4.7
31	5.0	.....	4.8	.....	3.75	.....	3.8	3.62	.....	3.7	.....	4.7
1901.[c]												
1	3.72	3.95	3.7	4.38	4.98	6.1	4.95	4.2	5.25	5.02	3.8	4.8
2	3.75	3.9	3.7	4.4	4.9	5.65	4.75	4.28	5.55	4.65	3.8	4.8
3	3.8	3.85	3.7	6.0	4.8	5.15	4.7	4.1	5.2	4.4	3.8	4.8
4	3.78	3.78	3.8	7.65	4.72	5.48	4.7	4.05	4.92	4.35	3.8	4.6
5	3.8	3.8	3.78	6.6	4.65	4.85	4.5	4.05	4.75	4.3	3.8	4.6
6	3.85	3.9	3.8	6.25	4.6	5.95	4.8	4.3	4.4	4.22	3.8	4.5
7	3.75	3.95	3.85	6.25	4.5	6.6	5.5	5.8	4.25	4.1	3.8	4.5
8	3.8	3.88	3.85	5.9	4.42	7.1	4.3	5.5	4.22	4.15	3.8	4.5
9	3.72	3.82	3.8	5.4	5.15	5.9	4.45	4.8	4.1	4.1	3.8	4.5
10	3.7	3.82	3.85	5.1	6.25	5.4	4.35	4.45	4.05	3.95	3.8	4.5
11	4.15	3.82	11.25	4.85	6.62	5.0	4.4	4.3	4.2	3.95	3.7	4.4
12	5.3	3.8	9.05	4.7	6.25	4.78	4.7	5.2	4.1	4.0	3.6	4.4
13	5.75	3.9	6.5	4.6	5.65	5.1	4.7	5.55	4.02	3.95	3.6	4.5
14	5.1	4.0	5.68	7.45	5.3	5.3	6.4	4.7	4.0	3.9	3.7	4.4
15	4.85	3.95	5.35	12.6	4.85	4.95	6.9	4.4	4.0	3.9	3.7	10.8
16	4.68	3.88	4.98	8.3	4.68	12.15	6.82	4.6	4.15	3.82	3.8	9.1
17	4.45	3.8	4.75	6.9	4.6	11.1	7.1	4.58	4.15	3.8	3.8	8.2
18	4.3	3.8	4.62	6.25	4.72	7.5	6.48	4.35	4.15	3.8	3.8	5.5
19	4.3	3.82	4.52	5.85	4.55	6.25	6.95	4.55	4.1	3.8	3.7	5.1
20	5.55	3.78	4.2	7.4	4.52	5.9	6.1	4.4	4.05	3.82	3.7	4.9
21	4.95	3.8	4.9	16.5	4.65	6.95	5.3	4.15	3.95	3.78	3.7	5.0
22	4.35	4.0	4.9	12.45	7.05	6.75	4.95	4.05	3.88	3.75	3.8	5.3
23	4.05	3.98	4.9	8.5	14.7	6.2	4.75	4.05	3.88	3.7	3.85	5.2
24	3.98	3.95	4.82	6.8	8.7	5.75	4.55	4.2	3.8	3.7	5.25	5.1
25	4.0	3.92	4.7	6.65	7.15	5.25	4.5	4.6	3.8	3.72	4.85	5.0
26	3.98	3.85	4.62	6.1	6.55	5.3	4.3	4.75	3.7	3.8	4.5	5.0
27	4.0	3.82	4.75	5.7	6.65	5.55	4.35	4.5	3.65	3.8	4.25	5.0
28	4.0	3.72	4.75	5.3	7.05	4.7	4.3	4.25	3.65	3.8	4.35	4.9
29	3.95	.....	4.55	5.1	7.2	5.4	4.15	4.3	5.15	3.82	4.05	5.1
30	3.92	.....	4.5	5.0	6.7	5.6	4.65	4.5	5.9	3.82	4.0	5.1
31	3.9	.....	4.45	.....	6.2	.....	4.35	4.9	.....	3.8	.....	4.9

[a] All gage heights June 26, 1899, to September 10, 1900, refer to 1906 datum. Datum lowered 1.00 foot September 10, 1900.

[c] River frozen January 1–14 and January 30 to February 6, 1900.

[d] Ice conditions during part of January and February, 1901; river frozen December 21 to 28, 1901.

summary of the records furnishes the following results: Maxi- discharge for twenty-four hours, 21,630 second-feet; minimum arge for twenty-four hours, 90 second-feet; mean annual rainfall ven years, 37.91 inches.

scharge measurements of North Fork of Shenandoah River near Riverton, Va.

Date.	[a] Gage height.	Discharge.	Date.	[a] Gage height.	Discharge.
1899.	*Feet.*	*Second-feet.*	1904.	*Feet.*	*Second-feet.*
ber 2	3.85	270	June 10	4.81	578
ber 2 [b]	3.85	287	July 1	4.71	480
			September 27	3.95	93
1900.			October 19	4.11	130
ry 13	4.25	645			
	6.30	2,923	1905.		
ber 10 [b]	3.60	146	April 3	5.18	645
			May 17	5.68	989
1901.			October 27	4.48	273
	5.95	2,410	December 27	5.60	961
1902.			1906.		
16	4.20	256	April 13	5.60	969
1903.					
21	4.40	388			

[a] All gage heights refer to 1905 datum. [b] Measured by wading.

aily gage height, in feet, of North Fork of Shenandoah River near Riverton, Va.

ay.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
9,[a b]												
							3.8	3.68	3.88	3.7	4.2	3.68
							3.8	3.68	3.88	3.68	3.95	3.7
							3.78	3.68	3.95	3.6	3.95	3.65
							3.8	3.7	3.85	3.65	3.95	3.65
							3.73	3.65	3.72	3.7	3.85	3.62
							3.78	4.0	3.72	3.68	3.8	3.6
							3.8	3.95	3.72	3.65	3.8	3.62
							3.8	3.95	3.7	3.65	3.8	3.65
							3.8	3.82	3.7	3.68	3.8	3.6
							3.8	3.8	3.7	3.7	3.8	3.62
							3.8	3.72	3.7	3.7	3.78	3.65
							3.78	3.7	3.72	3.7	3.75	3.68
							3.75	3.7	3.72	3.7	3.73	3.8
							3.75	3.72	3.7	3.7	3.7	3.85
							3.7	3.7	3.7	3.7	3.7	3.9
							3.68	3.78	3.68	3.65	3.7	3.9
							3.68	3.78	3.7	3.65	3.7	3.9
							3.78	3.78	3.68	3.7	3.7	3.9
							3.75	3.7	3.6	3.68	3.7	3.88
							3.7	3.65	3.8	3.7	3.7	3.8
							3.68	3.62	3.8	3.65	3.7	3.8
							3.68	3.62	3.8	3.65	3.7	3.8
							3.65	3.68	3.8	3.65	3.7	3.8
							3.58	3.65	3.8	3.65	3.7	3.8
							3.62	3.62	3.8	3.7	3.7	3.82
						3.85	3.7	3.65	3.8	3.7	3.7	3.88
						3.88	3.68	3.62	3.78	3.7	3.7	4.0
						3.88	3.85	3.7	3.75	3.7	3.7	4.0
						3.88	4.12	3.68	3.7	3.7	3.65	4.0
						3.8	3.8	3.95	3.7	3.68	3.68	4.0
							3.7	3.9		3.75		4.0

gage heights June 26, 1899, to September 10, 1900, refer to 1906 datum. Datum lowered 1.00 foot nber 10, 1900.
ver frozen December 26–31, 1899.

Daily gage height, in feet, of North Fork of Shenandoah River near Riverton, Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1900.[a] [b]												
1	4.0	5.0	5.05	4.7	4.25	3.8	3.9	3.72	3.6	3.8	3.7	4.5
2	4.0	5.0	7.85	4.58	4.17	3.8	3.9	3.65	3.6	3.8	3.72	4.6
3	4.0	5.0	6.55	4.52	4.15	3.8	3.85	3.6	3.62	3.75	3.7	4.6
4	4.0	5.0	5.4	4.48	4.1	3.9	3.78	3.55	3.62	3.7	3.75	4.6
5	4.0	4.9	5.1	4.4	4.05	3.88	3.72	3.52	3.58	3.7	3.7	4.1
6	4.0	4.5	4.88	4.32	4.05	3.82	3.72	3.5	3.6	3.7	3.7	3.7
7	4.0	4.38	4.82	4.28	4.0	3.8	3.7	3.5	3.6	3.78	3.7	3.5
8	4.0	4.1	4.75	4.25	3.98	3.8	3.7	3.55	6.58	3.8	3.7	4.7
9	4.0	4.0	4.68	4.2	3.95	3.8	3.68	3.58	3.6	3.7	3.65	4.6
10	4.0	3.95	4.6	4.15	3.92	3.8	3.68	3.6	3.6	3.7	3.62	4.6
11	4.0	4.0	4.5	4.15	3.9	3.75	3.62	3.6	3.6	3.68	3.7	4.5
12	4.0	3.98	4.42	4.15	3.9	3.72	3.62	3.58	3.6	3.65	3.6	4.0
13	4.0	4.12	4.38	4.15	3.9	3.7	3.62	3.5	3.58	3.7	3.6	3.8
14	3.98	5.1	4.35	4.15	3.9	3.72	3.65	3.5	3.6	3.7	3.68	3.8
15	3.92	5.2	4.35	4.1	3.9	3.75	3.62	3.5	3.6	3.7	3.65	4.0
16	3.9	4.87	4.35	4.1	3.82	3.78	3.6	3.55	3.7	3.7	3.6	3.8
17	3.8	4.62	4.3	4.1	3.8	4.45	3.68	3.6	3.68	3.78	3.6	4.0
18	3.8	4.42	4.25	4.1	3.8	5.75	3.62	3.6	3.65	3.8	3.62	3.9
19	3.92	4.35	4.5	4.2	3.8	5.75	3.6	3.55	3.68	3.75	3.62	3.9
20	4.92	4.35	6.95	4.55	3.8	4.98	3.6	3.55	3.6	3.7	3.65	3.7
21	7.3	4.25	8.2	4.6	3.8	4.62	3.62	3.5	3.6	3.7	3.7	3.7
22	5.65	4.75	6.7	4.6	3.8	4.3	3.7	3.62	3.58	3.7	3.62	3.6
23	4.9	6.98	5.9	5.22	3.8	4.2	3.82	3.6	3.58	3.7	3.6	3.5
24	4.55	6.3	5.42	5.4	3.8	4.15	5.28	3.6	3.6	3.75	3.68	3.5
25	4.25	5.63	5.18	5.1	3.8	4.08	4.32	3.6	3.6	3.78	3.7	3.5
26	4.02	5.15	5.0	4.75	3.8	4.0	4.22	3.6	3.6	3.85	4.65	3.5
27	4.0	4.9	5.0	4.62	3.8	3.92	4.0	3.55	3.6	3.9	7.0	3.5
28	4.0	4.8	4.9	4.5	3.8	3.9	3.92	3.6	3.62	3.8	5.25	3.5
29	4.5	.....	4.9	4.42	3.8	3.9	3.82	3.62	3.72	3.75	5.35	3.5
30	5.0	.....	4.85	4.32	3.8	3.9	4.08	3.6	3.95	3.72	4.45	3.5
31	5.0	.....	4.8	.....	3.75	.....	3.8	3.62	.....	3.7	.....	3.5
1901.[c]												
1	3.72	3.95	3.7	4.38	4.98	6.1	4.95	4.2	5.25	5.02	3.8	3.9
2	3.75	3.9	3.7	4.4	4.9	5.65	4.75	4.28	5.55	4.65	3.8	3.9
3	3.8	3.85	3.7	6.0	4.8	5.15	4.7	4.1	5.2	4.4	3.8	3.9
4	3.78	3.78	3.8	7.65	4.72	5.48	4.7	4.05	4.92	4.35	3.8	4.0
5	3.8	3.8	3.78	6.6	4.65	4.85	4.5	4.05	4.75	4.3	3.8	4.4
6	3.85	3.9	3.8	6.25	4.6	5.95	4.8	4.3	4.4	4.22	3.8	4.3
7	3.75	3.95	3.85	6.25	4.5	6.6	5.5	5.8	4.25	4.1	3.8	4.3
8	3.8	3.88	3.85	5.9	4.42	7.1	4.3	5.5	4.22	4.15	3.8	4.2
9	3.72	3.82	3.8	5.4	5.15	5.9	4.45	4.8	4.1	4.1	3.8	4.2
10	3.7	3.82	3.85	5.1	6.25	5.4	4.35	4.45	4.05	3.95	3.8	4.3
11	4.15	3.82	11.25	4.85	6.62	5.0	4.4	4.3	4.2	3.95	3.7	4.4
12	5.3	3.8	9.05	4.7	6.25	4.78	4.7	5.2	4.1	4.0	3.6	4.4
13	5.75	3.9	6.5	4.6	5.65	5.1	4.7	5.55	4.02	3.95	3.6	4.3
14	5.1	4.0	5.68	7.45	5.3	5.3	6.4	4.7	4.0	3.9	3.7	4.4
15	4.85	3.95	5.35	12.6	4.85	4.95	6.9	4.4	4.0	3.9	3.7	10.6
16	4.68	3.88	4.98	8.3	4.68	12.15	6.82	4.6	4.15	3.82	3.8	9.1
17	4.45	3.8	4.75	6.9	4.6	11.1	7.1	4.58	4.15	3.8	3.8	6.8
18	4.3	3.8	4.62	6.25	4.72	7.5	6.48	4.35	4.15	3.8	3.8	5.5
19	4.3	3.82	4.52	5.85	4.55	6.25	6.95	4.55	4.1	3.8	3.7	5.1
20	5.55	3.78	4.2	7.4	4.52	5.9	6.1	4.4	4.05	3.82	3.7	4.9
21	4.95	3.8	4.9	16.5	4.65	6.95	5.3	4.15	3.95	3.78	3.7	8.0
22	4.35	4.0	4.9	12.45	7.05	6.75	4.95	4.05	3.88	3.75	3.8	7.2
23	4.05	3.98	4.9	8.5	14.7	6.2	4.75	4.05	3.88	3.7	3.85	7.2
24	3.98	3.95	4.82	6.8	8.7	5.75	4.55	4.2	3.8	3.7	5.25	7.2
25	4.0	3.92	4.7	6.65	7.15	5.25	4.5	4.6	3.8	3.72	4.85	7.2
26	3.98	3.85	4.62	6.1	6.55	5.3	4.3	4.75	3.7	3.8	4.5	7.2
27	4.0	3.82	4.75	5.7	6.65	5.55	4.35	4.5	3.65	3.8	4.25	6.9
28	4.0	3.72	4.75	5.3	7.05	4.7	4.3	4.25	3.65	3.8	4.35	6.6
29	3.95	.....	4.55	5.1	7.2	5.4	4.15	4.3	5.15	3.82	4.05	6.3
30	3.92	.....	4.5	5.0	6.7	5.6	4.65	4.5	5.9	3.82	4.0	13.5
31	3.9	.....	4.45	.....	6.2	.....	4.35	4.9	.....	3.8	.....	8.2

[a] All gage heights June 26, 1899, to September 10, 1900, refer to 1906 datum. Datum lowered 1.00 foot September 10, 1900.

[c] River frozen January 1-14 and January 30 to February 6, 1900.

[d] *Ice conditions* during part of January and February, 1901; river frozen December 21 to 28, 1901.

Daily gage height, in feet, of North Fork of Shenandoah River near Riverton, Va.—Cont'd.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1902.[a]												
1	7.05	4.9							4.05	4.3	4.1	5.45
2	6.2	4.88							4.05	4.2	4.15	5.75
3	5.75	4.8							4.1	4.2	4.1	5.85
4	5.4	5.2							4.35	4.2	4.15	5.9
5	5.0	5.5							4.1	4.2	4.05	5.85
6	4.9	5.5							4.05	4.2	4.2	5.8
7	4.85	5.5							4.0	4.3	4.2	5.55
8	4.8	5.5							4.05	4.2	4.1	5.5
9	4.7	5.5							4.05	4.15	4.1	5.3
10	4.68	5.5							4.1	4.1	4.1	5.15
11	4.55	5.5							4.05	4.15	4.0	5.05
12	4.5	5.5							4.1	4.25	4.1	5.35
13	4.6	5.5							4.05	4.3	4.1	6.25
14	4.55	5.5							4.0	4.6	4.1	6.6
15	4.6	5.5							4.0	4.35	4.1	6.3
16	4.55	5.5						4.2	3.9	4.3	4.1	5.85
17	4.48	5.5						4.2	4.0	4.2	4.1	8.15
18	4.35	5.5						4.1	4.0	4.2	4.1	7.65
19	4.28	5.5						4.15	4.0	4.2	4.2	7.1
20	4.2	5.5						4.2	4.0	4.15	4.2	5.75
21	4.3	5.5						4.2	4.0	4.1	4.2	5.5
22	5.4	5.5						4.2	4.05	4.1	4.2	5.45
23	5.15	5.5						4.25	4.05	4.1	4.2	5.3
24	4.75	5.5						4.2	4.1	4.1	4.2	5.2
25	4.6	8.8						4.2	4.1	4.1	4.35	5.0
26	4.75							4.2	4.1	4.1	5.0	4.95
27	5.0							4.1	4.1	4.15	5.15	4.85
28	6.15							4.1	4.1	4.2	5.2	4.9
29	5.5							4.15	4.15	4.2	5.1	5.0
30	5.05							4.1	4.2	4.2	5.0	4.85
31	4.95							4.1		4.2		4.7
1903.[b]												
1	4.7		9.0	7.15	5.1	9.05	6.3	4.45	4.3	4.3	4.3	4.75
2	4.8		7.15	6.8	5.0	6.75	5.75	4.5	4.6	4.3	4.25	4.4
3	10.9		6.5	6.4	5.0	5.95	5.4	4.45	4.6	4.3	4.2	4.3
4	8.95		6.1	6.25	4.95	5.45	5.25	4.6	4.4	4.4	4.3	4.3
5	7.15		5.78	6.05	4.8	5.15	5.6	5.2	4.4	4.25	4.25	4.3
6	6.45		5.6	5.75	4.85	6.2	6.45	4.85	4.4	4.3	4.2	4.3
7	6.05		5.65	5.6	4.85	8.4	5.5	4.7	4.4	4.4	4.2	4.2
8	5.75		5.95	5.6	4.8	9.95	5.15	4.55	4.35	4.9	4.2	4.25
9	5.4	5.4	5.95	5.8	4.75	7.5	4.95	4.5	4.3	4.95	4.2	4.2
10	5.3	5.25	5.75	5.65	4.8	12.0	4.85	4.4	4.4	4.9	4.2	4.2
11	5.25	5.2	5.7	5.6	4.75	7.5	4.8	4.45	4.65	4.8	4.25	4.2
12	6.3	5.2	5.6	5.4	4.7	6.75	4.9	4.45	4.6	4.55	4.2	4.3
13	8.15	5.15	5.55	5.3	4.7	6.65	5.4	4.4	4.5	4.45	4.3	4.3
14	7.9	5.1	5.45	9.85	4.7	7.0	6.2	4.4	4.4	4.6	4.3	4.2
15	7.9	5.1	5.4	9.3	4.7	6.35	5.7	4.4	4.35	4.6	4.2	4.2
16	7.9	5.35	5.25	8.8	4.65	5.9	5.2	4.4	4.3	4.5	4.2	4.2
17	7.9	5.7	5.2	8.0	4.6	5.55	5.0	4.5	5.0	4.5	4.25	4.2
18	7.35	5.75	5.15	7.1	4.6	5.45	4.85	4.55	6.25	4.5	4.2	4.2
19	5.65	5.35	5.1	6.6	4.6	5.2	4.8	4.55	5.65	4.5	4.2	4.2
20	6.35	5.5	5.1	6.25	4.55	5.1	4.7	4.5	5.1	4.5	4.3	4.2
21	7.0	5.7	5.0	6.0	4.55	5.05	4.7	4.4	4.75	4.4	4.25	4.2
22	(c)	5.5	5.75	5.75	4.5	4.9	4.6	4.3	4.7	4.4	4.2	4.2
23	5.6	5.4	7.7	5.65	4.5	4.9	4.6	4.3	4.6	4.4	4.2	4.5
24	5.4	5.55	10.0	5.5	4.7	4.9	4.5	4.3	4.6	4.35	4.2	4.4
25	5.25	5.95	7.8	5.45	4.95	4.85	4.5	4.3	4.6	4.3	4.2	4.35
26	5.1	6.05	6.75	5.4	4.75	5.4	4.4	4.3	4.55	4.3	4.2	4.2
27	5.0	6.05	6.25	5.4	4.7	5.25	4.4	4.3	4.4	4.3	4.2	4.2
28	6.8	7.65	5.95	5.3	4.8	5.95	4.4	4.2	4.3	4.3	4.2	4.2
29			5.65	5.2	4.7	8.1	4.4	4.2	4.3	4.3	4.2	4.2
30			6.25	5.1	4.8	7.75	4.45	4.3	4.3	4.3	4.2	4.2
31			7.6		5.9		4.4	4.3		4.3		4.2

[a] River frozen February 4 to 24, 1902.
[b] River frozen January 12–28, December 16–23, 26–31, 1903.
[c] Freshet January 22, 1903; gage pushed over by ice.

Daily gage height, in feet, of North Fork of Shenandoah River near Riverton, Va.—Cont'd.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.[a]												
1	4.2	.....	.....	4.88	5.85	5.65	4.72	4.3	4.1	4.05	4.0	4.02
2	4.2	.....	.....	5.0	5.7	5.05	4.5	4.45	4.05	4.0	4.0	4.06
3	4.2	.....	.....	4.98	5.4	4.85	4.38	4.4	4.15	3.95	4.05	4.1
4	4.2	.....	.....	4.88	5.1	4.8	4.3	4.5	4.15	4.0	4.05	4.1
5	4.2	.....	4.7	4.8	5.05	4.85	4.35	4.5	4.1	4.1	4.0	4.1
6	4.2	.....	4.65	4.72	5.0	6.05	4.25	4.8	4.05	4.1	4.05	4.2
7	4.2	.....	4.7	4.72	4.9	6.7	4.32	4.5	4.05	4.0	4.05	4.2
8	4.2	.....	6.2	4.7	4.9	5.3	4.35	4.5	4.1	4.05	4.0	4.1
9	4.2	.....	6.2	4.75	4.9	4.95	4.4	4.45	4.05	4.0	4.0	4.1
10	4.2	.....	5.6	5.1	5.0	4.8	6.15	4.38	4.1	4.0	4.1	4.15
11	4.2	.....	5.15	5.38	4.95	4.72	6.82	4.4	4.1	4.0	4.1	4.2
12	4.2	.....	5.0	5.15	4.9	4.6	6.0	4.35	4.1	4.1	4.05	4.5
13	4.2	.....	4.9	5.0	4.8	4.5	5.75	4.35	4.05	4.0	4.1	4.5
14	4.2	.....	4.8	4.9	4.8	4.5	5.1	4.3	4.2	4.05	4.1	4.5
15	4.2	.....	4.78	4.8	4.75	4.4	4.85	4.2	4.2	4.0	4.05	4.5
16	4.2	.....	4.7	4.72	4.8	4.45	4.7	4.3	4.15	4.05	4.1	4.5
17	4.2	.....	4.7	4.65	4.7	4.45	4.55	4.2	4.15	4.05	4.1	4.5
18	4.2	.....	4.68	4.55	4.7	4.42	4.55	4.22	4.1	4.05	4.02	4.5
19	4.2	.....	4.6	4.58	4.78	4.5	4.5	4.2	4.1	4.0	4.0	4.5
20	4.2	.....	4.52	4.5	6.45	4.75	4.7	4.22	4.05	4.05	4.0	4.5
21	4.2	.....	4.55	4.45	5.7	5.25	4.55	4.2	4.25	4.05	4.0	4.5
22	4.2	.....	4.52	4.48	5.35	5.3	4.4	4.2	4.1	4.0	4.1	4.5
23	4.2	.....	4.65	4.4	5.15	4.85	4.38	4.3	4.05	4.1	4.1	4.5
24	(b)	.....	4.75	4.4	4.95	4.62	4.35	4.35	4.1	4.1	4.1	4.5
25	.....	.....	4.8	4.35	4.78	4.45	4.5	4.2	4.0	4.0	4.02	4.5
26	.....	.....	4.8	4.5	5.15	4.4	4.5	4.25	4.0	4.1	4.0	4.55
27	.....	.....	4.8	4.6	4.95	4.35	4.4	4.2	3.98	4.05	4.05	4.6
28	.....	.....	4.78	6.0	4.8	4.4	4.4	4.2	4.05	4.05	4.0	4.65
29	.....	.....	4.7	7.05	4.7	4.38	4.65	4.1	4.05	4.1	4.05	4.65
30	.....	.....	4.7	6.4	4.6	4.75	4.55	4.1	4.1	4.02	4.1	4.65
31	.....	.....	4.78	.....	4.8	.....	4.45	4.15	.....	4.05	.....	4.35
1905.[c]												
1	4.28	5.5	5.5	5.45	4.6	4.6	5.3	5.05	4.4	4.2	4.35	4.22
2	4.2	5.5	5.5	5.3	4.7	5.05	5.45	4.8	4.4	4.2	4.4	4.15
3	4.35	5.5	5.5	5.2	4.6	4.85	5.25	4.65	4.35	4.15	4.3	4.45
4	5.55	5.5	5.5	5.15	4.6	4.68	5.05	4.6	4.3	4.25	4.3	4.7
5	5.9	5.5	.....	5.15	4.52	4.55	5.3	4.6	4.38	4.2	4.38	5.05
6	5.9	5.5	5.8	5.6	4.6	4.5	6.9	4.48	4.45	4.15	4.35	4.9
7	5.9	5.5	5.75	5.8	4.6	4.9	5.75	4.4	4.4	4.15	4.35	4.72
8	.....	5.5	6.0	5.65	4.52	4.95	5.5	4.35	4.4	4.15	4.3	4.7
9	.....	5.5	6.4	5.5	4.55	4.7	5.7	4.38	4.35	4.15	4.22	4.55
10	.....	5.5	7.65	5.4	4.5	4.5	5.3	4.4	4.3	4.05	4.32	4.5
11	.....	5.5	7.45	5.25	4.5	4.42	5.35	4.4	4.28	4.25	4.38	4.42
12	.....	5.5	6.75	5.3	4.5	4.25	6.15	4.4	4.3	4.35	4.32	4.42
13	.....	5.5	6.4	5.25	4.5	4.65	5.75	4.32	4.3	4.25	4.28	4.42
14	.....	5.5	5.95	5.15	4.55	4.4	6.9	5.1	4.3	4.2	4.15	4.48
15	.....	5.5	5.75	5.1	5.45	4.4	7.1	4.7	4.28	4.2	4.22	4.38
16	.....	5.5	5.6	5.05	6.15	4.3	6.1	5.48	4.32	4.25	4.2	4.4
17	.....	5.5	5.5	4.98	5.65	4.2	5.5	5.45	4.32	4.25	4.18	4.55
18	.....	5.5	5.4	4.92	5.35	4.2	5.2	5.0	4.4	4.25	4.1	4.7
19	.....	5.5	5.4	4.9	5.2	4.25	5.05	4.8	4.32	4.2	4.18	4.62
20	.....	5.5	5.4	4.9	4.55	4.2	4.92	4.7	4.32	4.25	4.2	4.6
21	.....	5.5	5.95	4.8	4.92	6.2	4.8	4.6	4.28	4.2	4.15	7.3
22	.....	5.5	6.4	4.8	4.8	6.95	4.8	4.4	4.25	4.2	4.18	9.55
23	4.75	5.5	6.5	4.75	4.7	7.5	5.55	4.4	4.3	4.15	4.2	7.75
24	5.5	5.5	6.05	4.7	4.62	10.75	5.95	4.35	4.2	4.1	4.2	6.95
25	5.5	5.5	7.45	4.7	4.6	9.05	5.4	5.0	4.2	4.2	4.22	6.5
26	5.5	5.5	6.95	4.7	4.55	7.0	5.15	6.1	4.15	4.5	4.22	5.95
27	5.5	5.5	6.5	4.7	4.4	6.2	4.92	5.45	4.2	4.48	4.18	5.55
28	5.5	5.5	6.2	4.8	4.5	6.2	4.78	4.9	4.2	4.35	4.12	5.4
29	5.5	.....	5.9	4.8	4.42	5.7	4.75	4.75	4.2	4.3	4.2	5.7
30	5.5	.....	5.7	4.7	4.4	5.4	5.6	4.6	4.2	4.32	4.2	6.28
31	5.5	.....	5.55	.....	4.45	.....	5.7	4.5	.....	4.42	.....	6.0

[a] River frozen January 1-23, and December 12-26, 1904.
[b] Gage removed January 23, 1904, to protect from ice; replaced March 5, 1904.
[c] River frozen January 5 to March 4, 1905.

height, in feet, of North Fork of Shenandoah River near Riverton, Va.—Cont'd.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
...	5.7	5.3	4.55	7.9	5.65	4.62	5.05	.....	.....	.....	.....	.....
...	5.45	5.2	4.5	7.1	5.5	4.7	4.88	.....	.....	.....	.....	.....
...	5.4	5.1	4.75	6.7	5.4	4.58	4.85	.....	.....	.....	.....	.....
...	8.6	[a] 5.5	6.45	6.32	5.35	4.52	6.12	.....	.....	.....	.....	.....
...	7.75	5.0	6.55	6.1	5.25	4.65	5.52	.....	.....	.....	.....	.....
...	6.83	4.98	5.9	5.92	5.32	4.62	5.2	.....	.....	.....	.....	.....
...	6.2	[a] 5.15	5.55	5.75	5.32	4.55	4.95	.....	.....	.....	.....	.....
...	5.85	[a] 5.6	5.45	5.6	5.48	4.75	4.82	.....	.....	.....	.....	.....
...	5.58	[a] 5.5	5.35	5.52	5.45	4.62	4.7	.....	.....	.....	.....	.....
...	5.35	[a] 5.25	5.25	6.1	5.3	4.6	4.6	.....	.....	.....	.....	.....
...	5.37	[a] 5.45	5.15	5.95	5.22	4.85	4.6	.....	.....	.....	.....	.....
...	5.27	4.9	5.0	5.75	5.2	4.78	4.6	.....	.....	.....	.....	.....
...	5.25	4.68	5.0	5.62	5.05	4.65	4.65	.....	.....	.....	.....	.....
...	5.3	4.6	5.0	5.28	5.0	4.58	4.62	.....	.....	.....	.....	.....
...	5.4	4.68	5.05	6.4	4.9	5.05	.....	.....	.....	.....	.....	.....
...	5.48	4.65	5.2	6.98	4.88	5.25	.....	.....	.....	.....	.....	.....
...	5.4	[a] 4.8	5.45	6.4	4.82	5.5	.....	.....	.....	.....	.....	.....
...	5.38	4.55	5.58	6.05	4.8	5.85	.....	.....	.....	.....	.....	.....
...	5.33	4.52	5.8	5.88	4.8	5.9	.....	.....	.....	.....	.....	.....
...	5.27	4.6	5.9	5.7	4.72	5.65	.....	.....	.....	.....	.....	.....
...	5.2	4.6	5.95	5.58	4.62	6.85	.....	.....	.....	.....	.....	.....
...	5.1	4.6	6.2	5.48	4.6	7.25	.....	.....	.....	.....	.....	.....
...	5.05	4.6	6.55	5.4	4.6	6.6	.....	.....	.....	.....	.....	.....
...	5.7	4.6	6.45	5.28	4.55	5.8	.....	.....	.....	.....	.....	.....
...	5.9	4.53	6.2	5.2	4.55	5.55	.....	.....	.....	.....	.....	.....
...	5.55	4.55	6.1	5.2	4.52	5.3	.....	.....	.....	.....	.....	.....
...	5.33	4.52	7.5	7.48	4.52	6.1	.....	.....	.....	.....	.....	.....
...	5.3	4.58	9.4	6.7	5.08	6.2	.....	.....	.....	.....	.....	.....
...	5.37	.....	8.45	6.15	4.9	5.7	.....	.....	.....	.....	.....	.....
...	5.43	.....	8.35	5.85	4.75	5.35	.....	.....	.....	.....	.....	.....
...	5.35	.....	8.1	.....	4.65	.....	.....	.....	.....	.....	.....	.....

[a] Backwater due to ice conditions February 4, 7-11, and 17, 1906.

ating tables for North Fork of Shenandoah River near Riverton, Va.

JUNE 26, 1899, TO FEBRUARY 25, 1902.[a]

e t.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0	90	4.50	800	5.40	1,760	6.30	2,910
0	140	4.60	895	5.50	1,880	6.40	3,050
0	195	4.70	990	5.60	2,000	6.50	3,190
0	255	4.80	1,090	5.70	2,130	6.60	3,330
0	320	4.90	1,190	5.80	2,260	6.70	3,470
0	390	5.00	1,300	5.90	2,390	6.80	3,610
0	465	5.10	1,410	6.00	2,520	6.90	3,750
0	545	5.20	1,520	6.10	2,650	7.00	3,890
0	625	5.30	1,640	6.20	2,780	8.00	5,380
0	710						

e is strictly applicable only for open-channel conditions. It is based on six discharge ts made during 1899–1901. It is fairly well defined between gage heights 3.5 feet and 6.5 feet. bove gage height 8.0 feet were determined directly from the curve; no rating table was

Rating tables for North Fork of Shenandoah River near Riverton, Va.—Continued.

AUGUST 16, 1902, TO AUGUST 15, 1904.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.90	165	5.00	670	6.10	1,520	7.20	2,640
4.00	190	5.10	735	6.20	1,610	7.30	2,760
4.10	220	5.20	800	6.30	1,700	7.40	2,880
4.20	255	5.30	870	6.40	1,790	7.50	3,010
4.30	295	5.40	940	6.50	1,890	7.60	3,140
4.40	340	5.50	1,015	6.60	1,990	7.70	3,270
4.50	390	5.60	1,090	6.70	2,090	7.80	3,400
4.60	440	5.70	1,170	6.80	2,190	7.90	3,540
4.70	495	5.80	1,255	6.90	2,300	8.00	3,680
4.80	550	5.90	1,340	7.00	2,410		
4.90	610	6.00	1,430	7.10	2,520		

AUGUST 16, 1904, TO JULY 14, 1906.[b]

4.00	100	5.10	595	6.10	1,320	7.10	2,270
4.10	125	5.20	655	6.20	1,405	7.20	2,380
4.20	155	5.30	720	6.30	1,495	7.30	2,490
4.30	190	5.40	785	6.40	1,585	7.40	2,600
4.40	230	5.50	855	6.50	1,680	7.50	2,720
4.50	275	5.60	925	6.60	1,775	7.60	2,840
4.60	325	5.70	1,000	6.70	1,870	7.70	2,960
4.70	375	5.80	1,075	6.80	1,970	7.80	3,080
4.80	425	5.90	1,155	6.90	2,070	7.90	3,210
4.90	480	6.00	1,235	7.00	2,170	8.00	3,340
5.00	535						

[a] This table is strictly applicable only for open-channel conditions. It is based on four discharge measurements made during 1902, 1903, and the first half of 1904. It is fairly well defined between heights 4.2 feet and 4.8 feet. Estimates above gage height 8.0 feet were determined directly from curve.

[b] This table is strictly applicable only for open-channel conditions. It is based on seven discharge measurements made during the latter part of 1904 and 1905–1906, after the dam had been raised. well defined between gage heights 4.0 feet and 5.5 feet. Estimates above gage height 8.0 feet were determined directly from the curve. During August, 1904, the dam below the station was raised 2 feet. exact date is uncertain, so the table is assumed to apply from August 16, 1904.

Estimated monthly discharge of North Fork of Shenandoah River near Riverton, Va

[Drainage area, 1,040 square miles.[a]]

Month.	Discharge in second-feet.			Run-off.			Precipitat	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	L in
1899.								
January							2.52	
February							4.95	
March							5.12	
April							1.16	
May							4.95	
June 26–30	307	255	293	.282	.052		[b] 2.09	
July	481	130	228	.220	.254	10	2.51	
August	390	151	220	.212	.244	6	3.94	
September	355	140	227	.219	.244	6	3.78	
October	225	140	185	.178	.205	9	2.34	
November	545	168	238	.230	.257	32	.81	
December[c]	390	140	255	.246	.284	21	1.34	
The year							35.51	

[a] Drainage area of 1,040 square miles used to obtain run-off for 1906; 1,037 used for all other years.
[b] Precipitation for complete month, June, 1899.
[c] River frozen December 26–31, 1899; no correction made in estimates.

monthly discharge of North Fork of Shenandoah River near Riverton, Va.—Continued.

h.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
).								
.....	4,330	255	702	0.677	0.780	30	2.57	1.79
.....	3,862	355	1,128	1.09	1.14	31	3.73	2.59
.....	5,700	585	1,620	1.56	1.80	48	3.72	1.92
.....	1,760	465	765	.738	.823	43	1.89	1.07
.....	585	225	324	.312	.360	15	2.42	2.06
.....	2,195	195	504	.486	.542	9	5.98	5.44
.....	1,616	140	294	.284	.327	9	3.76	3.43
.....	207	90	128	.123	.142	7	1.93	1.79
.....	355	130	155	.149	.166	5	3.14	2.97
.....	320	168	219	.211	.243	8	3.19	2.95
.....	3,890	140	441	.425	.474	16	2.94	2.46
.....	2,650	140	548	.528	.609	33	1.83	1.22
ar.....	5,700	90	569	.549	7.41	20	37.10	29.69
.								
.....	2,195	195	627	.605	.698	30	2.31	1.61
.....	390	207	299	.288	.300	91	.33	.03
.....	10,960	195	1,391	1.34	1.54	41	3.80	2.26
.....	21,630	693	4,034	3.89	4.34	70	6.24	1.90
.....	17,850	728	2,653	2.56	2.95	51	5.82	2.87
.....	12,680	990	2,842	2.74	3.06	41	7.54	4.48
.....	4,030	505	1,499	1.44	1.66	38	4.38	2.72
.....	2,260	428	862	.831	.958	16	5.92	4.96
.....	2,390	168	684	.660	.736	20	3.78	3.05
.....	1,322	195	396	.382	.440	64	.69	.25
.....	1,580	140	363	.350	.390	19	2.01	1.62
.....	14,580	268	3,091	2.98	3.44	56	6.12	2.68
ear....	21,630	140	1,562	1.50	20.51	42	48.94	28.43
.								
.....	3,960	545	1,304	1.26	1.45	54	2.69	1.24
-25[d]....	6,660	1,090	1,909	1.90	1.77	.....	[e] 4.46	.....
.....	.....	.....	.....	.....	.....	.....	3.61	.....
.....	.....	.....	.....	.....	.....	.....	2.23	.....
.....	.....	.....	.....	.....	.....	.....	2.64	.....
.....	.....	.....	.....	.....	.....	.....	2.93	.....
.....	.....	.....	.....	.....	.....	.....	2.17	.....
31.....	275	220	243	.234	.139	.....	[e] 2.22	.....
.....	318	165	211	.204	.228	9	2.50	2.36
.....	440	220	259	.250	.288	8	3.65	3.36
.....	800	190	317	.306	.341	11	3.21	2.87
.....	3,890	495	1,228	1.18	1.36	40	3.38	2.02
ear....	.....	.....	.....	.....	.....	.....	35.78	.....
.								
28 [f g]	8,390	495	2,225	2.15	2.24	.....	[h] 4.08	.....
-28.....	3,205	735	1,127	1.09	.811	.....	[h] 3.49	.....
.....	6,860	670	1,750	1.69	1.95	47	4.15	2.20
.....	6,605	735	1,848	1.78	1.99	55	3.62	1.63
.....	1,340	390	549	.529	.610	23	2.69	2.08
.....	10,360	580	2,208	2.13	2.38	31	7.63	5.25
.....	1,840	340	736	.710	.819	27	3.06	2.24
.....	800	255	371	.358	.413	12	3.53	3.12
.....	1,655	295	464	.447	.499	21	2.42	1.92
.....	640	275	373	.360	.415	18	2.39	1.97
.....	295	255	265	.256	.286	35	.82	.53
.....	522	255	284	.274	.316	33	.96	.64
ear....	.....	.....	.....	.....	.....	.....	38.84	.....

[c] Frozen January 1-14 and January 30 to February 6, 1900; no correction made in estimates.
[d] Conditions during part of January and February, 1901; no correction made in estimates.
[e] Frozen December 21-28, 1901; no correction made in estimates.
[f] Frozen February 4-24, 1902; no correction made in estimates.
[g] Estimation for complete months, February and August, 1902.
[h] Frozen January 12-28, December 16-23, 26-31, 1903; no correction made in estimates.
[i] January 22, 1903. Gage pushed over by ice; discharge estimated.
[j] Estimation for complete months, January and February, 1903.

Estimated monthly discharge of North Fork of Shenandoah River near Riverton, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss, inch
1904.								
January 1–23[a]	255	255	255	0.246	0.210	.....	[b] 1.80	.....
February	.....	.....	.....	.....	.....	.....	1.26	.....
March 5–31	1,610	400	620	.598	.600	.....	[b] 2.08	.....
April	2,465	318	661	.637	.711	27	2.64	
May	1,840	440	718	.692	.798	23	3.45	
June	2,090	318	606	.584	.652	12	5.57	
July	2,212	295	554	.534	.616	12	5.04	
August	550	125	255	.246	.284	11	2.53	
September	172	96	124	.120	.134	7	1.95	
October	125	90	110	.106	.122	10	1.20	
November	125	100	112	.108	.120	13	.95	
December[a]	350	105	225	.217	.250	10	2.46	
The year	.....	.....	.....	.....	.....	.....	30.91	.....
1905.								
January 1–7, 23–31[c]	1,155	155	759	.732	.436	.....	[d] 3.39	.....
February [c]	855	855	855	.824	.858	44	1.95	
March [c e]	2,900	785	1,335	1.29	1.49	61	2.44	
April	1,075	375	596	.575	.642	37	1.74	
May	1,302	230	406	.392	.452	14	3.21	
June	7,450	155	1,042	1.00	1.12	17	6.54	
July	2,270	400	908	.876	1.01	16	6.29	
August	1,320	198	417	.402	.464	13	3.58	
September	252	140	192	.185	.206	14	1.50	
October	275	112	170	.164	.189	6	2.99	
November	230	125	172	.166	.185	22	.88	
December	5,575	140	889	.857	.988	26	3.81	
The year	.....	.....	.....	.....	.....	.....	38.31	.....
1906.								
January	4,160	565	1,036	.996	1.15	.....	.....	
February [f]	720	285	418	.402	.419	.....	.....	
March	5,350	275	1,421	1.37	1.58	.....	.....	
April	3,210	655	1,324	1.27	1.42	.....	.....	
May	962	285	545	.524	.604	.....	.....	
June	2,435	285	787	.757	.845	.....	.....	
July 1–14	1,337	325	523	.503	.262	.....	.....	

[a] River frozen January 1–23, and December 12–26, 1904; no correction made in estimates.
[b] Precipitation for complete months, January and March, 1904.
[c] River frozen January 5 to March 4, 1905; no correction made in estimates.
[d] Precipitation for complete month, January, 1905.
[e] Estimate March 5, 1905, interpolated.
[f] Backwater due to ice conditions February 4, 7–11, and 17, 1906; discharge corrected.

140
990
Cub Run
FISH DAM
145
Twomile Run
MILL DAM
970
750
FISH DAM
125
FISH DAM
MILL DAM
Grove Hill
MILL
820
FISH DAM
FERRY
95
FISH DAM
650
FISH DAM
FORD
Cabin Run
55
ROAD BRIDGE
Riverton
SOUTHERN R.R.
N. AND W. R.R.
450
Long Marsh Run
15
FROM HARI

SCELLANEOUS DISCHARGE MEASUREMENTS IN NORTH FORK OF SHENANDOAH RIVER BASIN.

The following miscellaneous discharge measurements have been de in the basin of North Fork of Shenandoah River:

Miscellaneous discharge measurements in North Fork of Shenandoah River Basin.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
1895.			*Feet.*	*Square feet.*	*Feet per sec.*	*Second-feet.*
ıst 7.....	North Fork of Shenandoah River.	300 feet below dam at county bridge and ¾ mile above junction with South Fork of Shenandoah River, near Riverton, Va.	.....	210	1.72	362
1897.						
ıber 4.....	.....do.....	.....do.....	150	100	1.40	140
Do.....	Happy Creek.....	200 feet above mouth, near Riverton, Va.	3.5	2.1	1.47	3.1
ıber 12.....	Cedar Creek.....	½ mile above mouth, near Strasburg, Va.	18	16	1.69	[a] 27
ıber 15.....	Passage Creek.....	At entrance to Fort Valley, near Riverton, Va.	8	3	2.00	6
ıber 7.....	Crooked Run.....	Near highway bridge, near Riverton and on road to Cedarville, Va.	6	6	.58	3.4

[a] Discharge increased by heavy rains of preceding night.

ENANDOAH RIVER BASIN BELOW NORTH AND SOUTH FORKS.

SLOPE.

The slope of the Shenandoah and South Fork from Harpers Ferry Port Republic, Va., is shown on Pl. III. The following table shows elevations above tide of a number of points on Shenandoah River:

Slope of Shenandoah River.

[Pl. III.]

Locality.	Distance from mouth.	Elevation above tide.	Distance between points.	Fall between points.	Fall per per mile between points.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*
pers Ferry, junction with Potomac.....	0.0	242	2.5	44	17.6
s Falls.....	2.5	286	5.5	40	7.3
r mouth of Evitts Creek.....	8.0	326	10.0	34	3.4
lemans Ferry.....	18.0	360	13.0	40	3.1
ys Ferry.....	31.0	400	23.0	53	2.3
fluence of North and South forks.....	54.0	[a] 453	96.0	586	6.1
th Fork, near Port Republic.....	150	1,039			

[a] Profiles of the Norfolk and Western Railway give this elevation as 445 feet.

SHENANDOAH RIVER AT MILLVILLE, W. VA.

The Millville station was established April 15, 1895, by C. C. Babb. is located about one-fourth mile above the Baltimore and Ohio ilroad station at Millville, W. Va. The highway runs within a rods of the stream at the gaging station. The station is best ched by driving from Harpers Ferry, W. Va.

The channel is straight for several hundred feet above and below station, and the current is swift and unobstructed. Both banks low and liable to overflow. There is but one channel at all ges. The bed of the stream is composed of mud and rocks.

Daily gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897.[a]												
1	1.6	1.1	3.8	2.1	1.5	1.6	1.1	1.1	0.7	0.5	0.9	0.8
2	1.5	1.1	3.6	2.1	1.8	1.6	1.0	1.0	.7	.5	.9	.8
3	1.4	1.6	3.6	2.0	9.35	1.5	1.0	.9	.7	.5	.9	.7
4	1.4	2.0	3.6	2.0	7.2	1.7	1.0	.9	.6	.5	1.1	.8
5	1.3	2.2	3.6	2.2	5.2	1.7	1.1	.9	.6	.5	1.4	1.0
6	1.3	2.2	3.6	2.4	4.7	1.9	1.0	1.5	.6	.5	1.1	1.5
7	1.3	.....	3.4	2.3	3.6	1.8	.8	.9	.5	.35	.8	1.2
8	1.2	.....	3.3	2.4	3.2	1.7	.8	.9	.5	.35	.8	1.1
9	1.2	.....	3.0	2.4	2.9	1.5	.8	.9	.5	.35	.7	.9
10	1.1	6.1	2.8	2.4	2.5	1.6	.8	.8	.4	.35	.8	.9
11	1.1	5.4	2.7	2.4	2.4	1.4	.....	1.2	.4	.4	.7	.8
12	1.1	4.8	2.6	2.4	2.4	1.4	1.1	1.0	.4	.5	.7	.9
13	1.4	4.1	2.6	2.3	2.5	1.4	1.0	.9	.4	.5	.5	.9
14	1.4	6.0	2.8	2.3	4.35	1.3	1.0	.8	.4	.5	.5	1.0
15	1.3	4.7	2.8	2.3	6.6	1.3	1.2	.7	.4	.5	.7	1.7
16	1.2	5.75	3.5	2.2	4.9	1.3	.9	.7	.4	.5	.65	2.4
17	1.1	5.9	3.6	2.2	3.9	1.3	.9	.7	.4	.5	.7	2.7
18	1.1	5.3	3.4	2.1	3.5	1.2	.9	.7	.4	.45	.6	2.2
19	1.1	4.9	3.2	2.1	3.2	1.2	.8	.6	.4	.4	.6	1.8
20	1.1	4.6	3.2	2.0	2.9	1.6	1.9	.6	.4	.4	.5	1.6
21	1.1	4.5	3.6	1.9	2.6	1.6	2.6	.6	.4	.45	.6	1.3
22	1.2	6.45	3.4	1.8	2.4	1.4	2.6	.6	.4	.5	.6	1.3
23	1.2	10.05	3.3	1.8	2.3	1.3	1.8	.6	.4	.5	.6	1.3
24	1.2	10.05	3.2	1.7	2.2	1.2	1.5	1.0	.6	.55	.55	1.3
25	1.1	6.7	3.0	1.7	2.2	1.1	1.3	1.3	1.2	.7	.5	1.3
26	1.1	5.5	2.9	1.6	2.2	1.1	1.2	1.0	.5	.8	.5	2.0
27	1.1	4.6	2.7	1.5	1.8	1.1	1.1	.9	.5	.9	.8	1.5
28	1.1	4.6	2.5	1.5	1.6	1.0	1.2	.8	.5	.8	.9	1.6
29	1.1	.....	2.4	1.4	1.6	1.0	1.5	.7	.4	.8	.7	1.5
30	1.1	.....	2.1	1.4	1.6	.9	1.3	.7	.4	.8	.6	1.2
31	1.0	.....	2.0	.....	1.6	.....	1.1	.8	.....	.9	.....	1.1
1898.[b]												
1	1.5	2.1	1.1	4.0	2.3	1.9	1.2	2.2	1.5	.9	2.8	2.1
2	1.3	2.1	1.1	3.9	2.2	1.8	.....	1.4	1.5	.9	2.4	2.1
3	1.2	1.8	1.1	3.2	2.0	1.7	.8	1.2	1.55	1.0	2.5	2.1
4	1.4	1.7	1.1	3.0	1.9	1.6	.8	1.4	1.5	1.0	2.7	2.5
5	1.0	2.1	1.0	2.8	1.7	1.6	.9	3.6	1.4	1.2	2.1	5.4
6	1.2	1.6	1.1	2.6	1.7	1.6	.9	8.3	1.4	1.8	2.0	6.0
7	.9	1.8	1.0	2.4	2.0	1.4	.9	4.1	1.4	1.5	2.0	4.6
8	1.3	1.8	1.0	2.3	6.3	1.3	.9	1.9	1.4	1.7	1.9	3.8
9	.9	1.6	1.0	2.2	8.9	1.2	.9	3.9	1.3	1.5	1.9	3.0
10	1.1	1.3	.9	2.0	7.4	1.1	.9	6.6	1.3	1.4	1.8	2.8
11	1.6	1.3	.9	1.8	5.4	1.1	.8	[c]11.7	1.1	1.3	1.9	2.6
12	1.2	1.3	.9	1.7	4.4	1.1	.7	10.0	1.1	1.2	1.8	2.4
13	2.0	1.1	.9	1.7	3.7	1.0	.7	6.0	1.1	1.0	1.7	2.4
14	1.9	1.1	.9	1.7	3.3	1.4	.7	5.1	1.1	1.0	1.8	2.2
15	2.0	1.1	.9	2.2	2.9	1.4	.7	4.1	1.0	1.0	1.7	1.9
16	3.6	1.0	.9	4.5	2.8	1.4	.7	3.9	1.0	1.0	1.7	2.2
17	2.9	.9	1.1	5.6	2.7	1.3	.7	3.6	1.0	1.1	1.7	2.1
18	2.6	.9	2.3	4.4	2.4	1.4	.7	3.4	1.1	1.1	1.7	2.2
19	2.1	1.0	2.0	3.8	2.2	1.9	.8	2.8	1.0	7.75	1.8	2.3
20	2.1	1.0	2.1	3.4	2.1	1.8	.9	3.4	1.0	8.4	2.3	2.0
21	2.1	1.0	2.1	2.8	2.0	1.5	1.1	2.7	1.0	5.0	2.7	2.0
22	2.0	1.3	2.0	2.6	2.0	1.7	1.1	2.4	1.0	5.0	2.5	2.0
23	2.0	1.3	1.9	2.4	2.4	1.4	1.0	2.3	1.1	9.1	2.5	2.3
24	2.3	1.3	1.9	2.2	2.9	1.4	.9	2.1	1.1	5.7	2.5	2.9
25	2.3	1.2	2.9	2.1	3.4	1.5	1.6	2.0	1.1	4.4	2.3	4.0
26	2.2	1.2	3.1	2.1	2.9	1.2	1.5	2.0	1.4	3.5	2.3	3.5
27	2.6	1.1	2.9	2.1	2.4	1.1	1.5	1.6	1.2	3.4	2.2	3.0
28	2.4	1.1	2.6	2.3	2.4	1.1	1.4	1.8	1.1	2.2	2.0	2.8
29	2.2	.....	2.6	2.2	2.4	1.1	1.4	1.6	1.1	3.0	2.0	2.5
30	1.5	.....	2.9	2.2	2.1	1.1	2.6	1.6	1.0	2.9	2.2	2.4
31	1.8	.....	3.4	.....	1.9	.....	2.1	1.6	.....	2.9	.....	2.3

[a] Ice conditions during January and December 24–31, 1897.
[b] Ice conditions during February, 1898.
[c] Gage height estimated August 11, 1898.

y gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.
	2.5	2.3	.....	3.1	1.7	2.05	0.9	1.0	1.1	0.8	1.55	0.8
.....	2.2	2.1	.....	3.0	1.6	2.35	.9	.8	.9	.7	2.75	.8
.....	2.8	1.7	.....	2.8	1.6	3.0	.8	.9	.9	.7	3.2	.75
.....	2.6	2.0	.....	2.7	1.6	2.1	.8	1.3	1.1	.7	2.4	.7
.....	3.3	2.4	.....	2.6	2.0	1.8	.8	.9	.8	.7	1.9	.75
.....	3.8	2.5	.....	2.5	1.9	1.5	.8	.8	.7	.7	1.8	.7
.....	4.6	2.3	.....	2.4	1.9	1.4	.7	1.1	.8	.7	1.6	.7
.....	6.7	2.5	.....	2.5	1.8	1.4	.8	1.0	.7	.7	1.4	.7
.....	5.0	2.5	.....	3.1	2.0	1.5	.9	1.2	.7	.8	1.3	.7
.....	4.5	2.3	5.0	3.0	2.3	1.4	1.0	1.0	.7	.8	1.2	.7
.....	3.8	2.4	5.5	2.9	3.1	1.3	.9	1.6	.8	.7	1.1	.7
.....	3.5	.....	5.2	2.7	2.8	1.4	.8	.9	1.2	.8	1.0	.75
.....	3.3	.....	4.6	2.6	2.6	1.4	.8	.8	.9	.7	1.0	.9
.....	3.0	2.3	4.0	2.5	2.7	1.3	.7	.9	.8	.7	1.0	2.9
.....	2.9	2.4	4.0	2.4	2.2	1.3	.7	.8	.8	.7	.9	2.2
.....	3.0	2.5	4.0	2.3	2.1	1.3	.9	.7	.7	.6	.9	1.9
.....	2.9	2.7	4.5	2.2	1.9	1.2	.8	.8	.7	.6	.9	1.6
.....	2.9	3.0	3.9	2.2	1.9	1.1	.7	.8	.6	.6	.8	1.4
.....	2.9	3.0	3.8	2.2	2.5	1.0	.7	.8	.6	.6	.9	1.3
.....	2.8	3.4	3.8	2.2	2.3	1.0	.7	.7	.8	.6	.8	1.2
.....	2.6	4.0	3.8	2.2	2.0	1.0	.7	.7	.9	.6	.8	1.2
.....	2.4	.....	3.7	1.9	1.9	.9	.7	.6	.9	.6	.8	1.1
.....	2.4	.....	3.5	1.9	1.7	1.0	.6	.6	1.5	.6	.8	1.1
.....	2.4	.....	3.3	1.9	1.7	.9	.6	.6	1.1	.6	.8	1.1
.....	2.4	.....	3.1	1.8	1.6	.9	.7	.5	1.0	.6	.8	1.3
.....	2.3	.....	3.0	2.0	1.5	.9	.6	.5	.9	.5	.85	1.2
.....	2.5	.....	2.9	1.9	1.5	.9	.6	.6	.9	.6	.85	1.7
.....	2.3	.....	2.9	1.8	1.4	.9	.6	.7	.9	.6	.8	1.4
.....	2.2	.....	3.0	1.8	1.4	.9	.6	.8	.8	.6	.8	1.65
.....	2.1	.....	3.6	1.7	1.3	1.0	1.5	1.0	.8	.6	.8	1.1
.....	2.1	.....	3.3	.....	1.6	.....	1.0	1.3	.....	.7	.....	1.1
.....	1.25	2.1	3.0	2.55	1.8	1.5	1.3	1.15	.6	.6	.8	2.0
.....	1.3	1.2	4.8	2.5	1.75	1.5	1.25	1.0	.6	.7	.8	1.7
.....	1.2	1.6	6.5	2.4	1.7	1.3	1.25	1.05	.6	.7	.8	1.5
.....	1.15	1.55	4.8	2.25	1.6	1.3	1.2	1.0	.6	.7	.9	1.6
.....	1.2	[b]2.0	3.9	2.2	1.6	1.3	1.2	.9	.55	.6	.9	2.25
.....	1.3	[b]2.0	3.4	2.1	1.5	1.25	1.3	.85	.5	.55	.9	4.8
.....	1.3	1.5	2.9	2.0	1.5	1.15	1.1	.8	.5	.5	.85	3.6
.....	1.3	1.4	2.8	1.9	1.4	1.1	1.0	.75	.45	.5	.9	2.8
.....	1.2	1.4	2.7	1.85	1.4	.95	.9	.7	.45	.75	.85	3.4
.....	1.15	1.4	2.6	1.8	1.4	1.0	.85	.7	.45	.6	.8	2.2
.....	1.2	1.4	2.5	1.7	1.3	.95	.8	.7	.45	.55	.8	1.9
.....	1.1	1.4	2.4	1.7	1.3	.9	.8	.65	.45	.5	.8	1.75
.....	1.3	1.5	2.3	1.7	1.3	1.0	.8	.7	.4	.5	.8	1.6
.....	1.4	1.9	2.2	1.7	1.2	.9	.75	.6	.4	.7	.75	1.5
.....	1.5	3.8	2.1	1.7	1.2	1.1	.75	.6	.4	.9	.75	1.4
.....	1.3	3.3	2.1	1.6	1.15	1.3	.7	.55	.5	1.1	.75	1.35
.....	1.2	2.8	2.1	1.6	1.1	2.3	.7	.6	.6	.9	.7	1.3
.....	1.15	2.5	2.0	1.55	1.1	2.7	.65	.6	.55	.8	.7	1.2
.....	1.2	2.3	2.0	1.6	1.2	4.5	.65	.6	1.1	.8	.65	1.15
.....	1.8	2.2	3.3	1.65	1.1	3.7	1.2	.6	.8	.7	.65	1.15
.....	6.0	2.5	5.95	2.1	1.9	3.0	.8	.65	.7	.6	.6	1.1
.....	5.9	2.45	6.2	2.4	1.9	2.6	1.0	.6	.6	.55	.65	1.0
.....	4.2	4.35	4.7	2.55	1.7	2.1	1.1	.55	.55	.5	.7	1.0
.....	3.3	5.9	3.9	3.0	1.6	1.9	1.4	.6	.55	.65	.7	1.0
.....	2.8	4.5	3.45	3.0	1.4	1.7	2.5	.6	.5	.8	.7	1.0
.....	2.5	3.8	3.15	2.7	1.25	1.55	2.8	.55	.5	2.1	1.1	1.0
.....	2.25	3.4	3.0	2.5	1.5	1.45	1.7	.65	.45	1.6	2.1	.95
.....	2.0	2.8	2.95	2.3	1.5	1.4	1.5	.7	.5	1.25	4.5	.9
.....	1.9	.....	2.8	2.15	1.5	1.35	1.3	.6	.55	1.1	3.15	.9
.....	1.8	.....	2.7	2.0	1.4	1.3	1.3	.6	.65	.95	2.45	.9
.....	1.85	.....	2.6	.....	1.3	.....	1.2	.6	.....	.9	.....	.9

ıditions January 1 to February 21, 1899. River frozen February 22 to March 9, 1899; no read-
ı.
ater from ice February 5–6, 1900.

Daily gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.[a]												
1	0.9	1.5	0.7	2.0	3.0	4.7	3.5	1.8	2.8	3.7	0.95	1.1
2	.9	1.6	.7	1.95	2.8	4.2	2.7	1.6	3.3	2.8	.95	1.2
3	.9	1.1	.7	2.5	2.7	3.7	2.4	1.5	3.0	2.4	.9	1.2
4	.95	1.0	.75	4.7	2.5	3.35	2.2	1.45	2.8	2.1	.9	1.5
5	.7	1.2	.75	5.7	2.4	3.3	1.15	1.4	2.3	1.8	.9	1.7
6	.9	2.3	.75	4.6	2.3	3.6	2.0	1.7	2.0	1.7	.9	1.8
7	.7	1.6	.8	4.2	2.2	4.1	2.5	2.1	1.9	1.5	.85	1.9
8	.8	1.6	.7	4.15	2.1	4.9	2.6	5.1	1.8	1.5	.85	1.8
9	.7	1.2	.8	3.6	2.1	4.5	2.0	3.8	1.6	1.5	.85	1.7
10	.8	1.2	.8	3.2	5.5	3.7	1.9	2.7	1.5	1.4	.85	1.7
11	.9	1.2	1.7	2.85	3.25	3.1	1.8	2.2	1.45	1.4	.85	1.7
12	2.1	.9	7.3	2.6	4.2	2.8	1.85	2.3	1.5	1.35	.85	1.7
13	2.3	1.2	5.3	2.4	3.5	2.6	2.1	3.1	1.9	1.35	.85	2.0
14	3.5	1.3	3.9	3.0	3.0	3.5	3.0	3.4	1.6	1.4	.8	2.0
15	2.9	1.3	3.2	10.25	2.7	2.9	4.3	2.6	1.5	1.35	.8	7.8
16	2.4	1.5	2.75	9.6	2.5	5.8	5.8	2.2	1.6	1.3	.8	10.5
17	2.1	1.0	2.4	6.1	2.3	10.1	5.2	2.75	1.5	1.2	.8	6.2
18	1.9	.9	2.2	4.9	2.25	5.7	4.2	2.6	1.5	1.1	.8	4.7
19	1.8	.8	2.0	4.8	2.2	4.6	4.3	2.6	1.45	1.1	.8	3.8
20	1.4	.8	1.8	4.6	2.15	3.9	3.9	2.6	1.4	1.1	.8	3.3
21	1.4	.8	2.0	10.55	2.0	3.5	3.5	2.2	1.3	1.0	.8	2.8
22	1.5	.9	2.2	(b)	2.5	5.7	3.2	2.1	1.25	1.0	.8	1.2
23	1.4	.9	2.4	8.5	11.1	5.5	2.7	2.0	1.2	1.0	1.0	1.2
24	1.3	.8	2.55	6.5	8.4	3.8	2.4	1.9	1.2	1.1	2.4	2.1
25	1.3	.9	2.3	5.3	6.3	3.2	2.2	2.2	1.15	1.0	2.7	2.4
26	1.3	.6	2.1	4.8	6.0	2.9	2.0	2.1	1.15	1.0	2.3	1.8
27	1.3	.8	2.1	4.3	6.7	2.9	2.1	2.2	1.1	1.0	1.8	2.3
28	1.3	.8	2.1	3.9	6.2	3.1	1.85	2.5	1.1	1.0	1.7	2.7
29	1.5	.....	2.6	3.5	6.3	2.7	1.8	2.6	1.3	1.0	1.5	4.0
30	1.4	.....	2.4	3.2	5.6	3.0	1.8	2.3	5.3	1.0	1.3	10.8
31	1.2	.....	2.15	.....	4.9	.....	1.85	3.0	.....	1.0	.....	9.
1902.[c]												
1	7.4	3.1	14.5	3.75	2.2	1.45	1.3	.9	.65	.9	.8	2.7
2	5.3	2.85	9.0	3.4	2.15	1.4	1.2	1.5	.65	.85	.8	2.6
3	4.5	3.0	7.2	3.2	2.2	1.35	1.15	1.9	.6	.8	.8	3.1
4	4.0	3.0	5.7	3.1	2.25	1.3	1.1	1.7	.6	.7	.8	3.3
5	3.5	2.8	5.0	2.9	2.1	1.3	1.05	1.3	.6	.9	.75	4.5
6	3.25	2.5	4.5	2.8	2.05	1.3	1.1	1.2	.65	1.0	.75	3.4
7	3.0	2.8	4.2	2.6	2.0	1.4	1.1	1.1	.6	.8	.7	3.7
8	2.85	2.7	4.2	2.8	4.0	1.25	1.05	1.05	.55	.75	.7	3.2
9	2.75	2.2	5.5	6.0	2.7	1.2	1.05	1.0	.6	1.1	.7	2.9
10	2.6	2.2	7.8	6.9	2.4	1.2	1.0	.9	.55	1.0	.65	2.6
11	2.5	2.1	8.0	7.2	2.1	1.15	.95	.8	.55	.9	.65	2.4
12	2.4	2.2	7.4	6.2	2.0	1.1	.9	.8	.55	1.0	.6	2.2
13	2.25	2.1	7.2	5.6	2.0	1.1	.9	.8	.5	1.2	.65	2.0
14	2.4	2.0	7.0	5.0	1.95	1.0	.9	.8	.5	1.75	.7	2.4
15	2.2	2.1	6.0	4.4	1.9	1.1	.8	.8	.55	1.55	.65	2.4
16	2.1	1.5	5.0	3.9	1.8	1.2	.8	.75	.55	1.3	.6	2.4
17	2.0	1.9	5.2	3.6	1.7	1.2	.8	.7	.5	1.15	.65	2.4
18	1.9	2.0	5.9	3.4	1.7	1.1	.8	.7	.5	1.0	.8	2.3
19	1.85	2.0	5.0	3.2	1.75	1.6	.75	.85	.5	.95	.8	2.0
20	1.8	1.7	4.4	3.0	1.8	1.4	.75	.8	.55	.9	.9	2.5
21	1.9	1.0	4.1	2.8	1.75	1.2	.8	.8	.6	.85	.8	3.1
22	3.2	2.4	3.8	2.7	1.7	1.2	.8	.8	.6	.8	.9	2.9
23	3.4	4.5	3.5	2.6	1.65	1.1	.8	.8	.6	.75	1.0	2.7
24	2.9	3.9	3.2	2.5	1.6	1.1	.75	.8	.55	.7	1.0	2.5
25	2.5	4.7	3.1	2.4	1.6	1.2	.75	.75	.55	.7	1.0	2.3
26	2.3	(d)	2.95	2.3	1.6	1.2	.8	.75	.6	.7	1.2	2.2
27	2.5	(d)	2.8	2.25	2.2	1.15	1.0	.7	.6	.65	2.0	2.1
28	3.6	11.0	2.75	2.2	1.75	1.1	.9	.7	.6	.9	2.5	2.1
29	4.4	.....	3.0	2.2	1.6	1.3	1.3	.7	.65	.85	2.4	2.1
30	3.6	.....	3.8	2.2	1.55	1.4	1.3	.65	1.0	.8	2.1	1.9
31	3.3	.....	3.9	.....	1.5	.....	1.4	.65	.....	.8	.....	1.8

[a] Water backed by ice during part of January and February, 1901.
[b] No reading; river out of banks April 22 and December 31, 1901.
[c] Ice conditions during part of February, 1902.
[d] Flood; no observation February 26–27, 1902.

ly gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued

.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	1.7	4.0	7.2	6.4	2.5	4.4	4.6	1.3	1.2	1.1	0.9	0.7
.....	1.7	3.6	6.5	5.0	2.4	3.8	4.2	1.35	2.2	1.1	.9	.7
.....	6.1	3.3	5.0	4.4	2.3	3.2	3.0	1.3	2.7	1.1	.9	.7
.....	8.7	3.3	4.2	4.1	2.2	2.5	2.75	1.5	2.05	1.05	.9	.65
.....	5.9	3.8	3.8	3.9	2.15	2.2	2.5	1.6	1.7	1.05	.95	.6
.....	4.75	4.2	3.5	3.7	2.1	2.0	3.4	1.9	1.55	1.0	1.0	.6
.....	4.0	3.7	3.25	3.5	2.1	3.9	4.65	2.0	1.45	1.0	.9	.6
.....	3.5	3.3	3.2	3.3	2.05	9.2	3.7	1.7	1.3	1.8	.9	.55
.....	3.1	2.7	3.6	3.3	2.0	6.5	2.3	1.5	1.25	2.1	.9	.6
.....	2.8	2.5	3.4	3.3	1.9	8.9	2.0	1.55	1.2	2.0	.9	.8
.....	2.7	2.3	3.3	3.2	1.85	4.9	1.95	1.4	1.2	1.8	.9	.7
.....	2.7	2.1	3.2	3.0	1.8	4.6	1.9	1.4	1.3	1.65	.9	.7
.....	2.2	2.3	3.2	3.1	1.75	4.0	2.7	1.35	1.2	1.55	.9	.7
.....	2.3	2.7	3.0	5.4	1.7	4.3	2.6	1.3	1.2	1.5	.85	.8
.....	2.0	2.6	2.95	7.8	1.7	3.6	2.8	1.3	1.2	1.4	.85	.8
.....	2.3	2.6	2.8	6.6	1.65	3.1	2.7	1.25	1.1	1.3	.85	[a]1.1
.....	2.2	3.3	2.7	6.1	1.65	2.8	2.2	1.25	1.3	1.3	.9	.5
.....	2.35	4.6	2.6	5.0	1.6	2.6	2.0	1.2	2.1	1.25	.9	.7
.....	2.3	4.1	2.55	4.4	1.55	2.4	1.9	1.5	4.6	1.2	.85	.8
.....	1.95	3.6	2.5	3.9	1.55	2.1	1.8	1.45	3.1	1.2	.85	.9
.....	2.2	3.4	2.5	3.7	1.5	2.0	1.7	1.3	2.7	1.2	.85	1.1
.....	3.5	3.3	2.5	3.6	1.5	2.0	1.65	1.25	2.2	1.15	.85	1.0
.....	6.0	3.0	4.1	3.3	1.5	1.9	1.6	1.2	1.8	1.1	.8	1.2
.....	3.4	3.0	7.3	3.1	1.5	1.9	1.55	1.1	1.6	1.05	.8	1.4
.....	2.8	3.2	7.6	3.0	1.5	1.85	1.5	1.05	1.5	1.0	.8	1.2
.....	2.6	3.5	5.7	2.9	1.8	1.8	1.5	1.0	1.4	1.0	.8	.8
.....	2.3	3.5	4.3	2.8	1.8	2.65	1.45	.95	1.3	1.0	.75	.9
.....	3.35	4.0	3.8	2.7	1.7	3.2	1.35	1.1	1.25	.95	.7	1.0
.....	6.9	.....	3.4	2.65	1.7	5.2	1.3	1.8	1.2	.95	.6	.9
.....	5.2	.....	3.4	2.55	1.85	5.7	1.25	1.25	1.15	.95	.6	.8
.....	4.5	.....	5.5	.....	2.05	.....	1.25	1.2	.....	.95	.....	.8
[b]												
.....	.8	.....	.....	1.8	3.3	4.0	1.5	1.15	.6	.45	.45	.45
.....	.85	.....	.....	1.8	3.3	2.6	1.4	1.05	.6	.4	.45	.45
.....	1.2	.....	.....	1.75	2.7	2.3	1.3	1.1	.6	.4	.4	.5
.....	1.2	.....	.....	1.7	2.4	2.1	1.2	1.25	.6	.4	.5	.5
.....	1.0	.....	.....	1.6	2.15	2.6	1.1	1.4	.6	.4	.45	.5
.....	1.0	.....	.....	1.5	2.1	2.85	1.2	1.4	.6	.4	.45	.55
.....	1.1	.....	.....	1.5	1.95	4.0	1.15	1.7	.6	.45	.45	.5
.....	1.1	.....	2.3	1.5	2.0	2.9	1.3	1.8	.6	.45	.45	.5
.....	1.3	.....	4.9	1.6	2.0	2.4	1.25	1.45	.55	.4	.4	.5
.....	1.2	.....	3.5	1.7	2.3	2.15	1.35	1.4	.55	.4	.4	.5
.....	1.2	.....	3.0	2.45	2.5	2.0	5.6	1.35	.5	.4	.5	.85
.....	1.1	.....	2.5	2.4	2.45	1.85	3.7	1.4	.5	.5	.45	.5
.....	1.1	.....	2.3	2.2	2.3	1.75	2.8	1.35	.6	.5	.5	.65
.....	1.0	.....	2.0	2.0	2.05	1.5	2.1	1.3	.6	.55	.6	.65
.....	1.0	.....	1.9	1.75	1.9	1.4	1.75	1.1	.9	.5	.6	.75
.....	1.0	.....	1.8	1.65	1.85	1.35	1.5	1.05	.9	.5	.5	.6
.....	1.0	.....	1.75	1.6	1.8	1.4	1.4	1.0	.8	.5	.5	1.65
.....	1.0	.....	1.7	1.55	1.8	1.65	1.3	1.0	.75	.5	.5	1.8
.....	1.1	.....	1.6	1.45	1.9	1.4	1.3	.95	.7	.5	.55	1.55
.....	1.1	.....	1.5	1.45	2.3	1.35	1.2	.9	.65	.45	.5	.8
.....	1.3	.....	1.45	1.3	3.5	1.6	1.2	.9	.6	.6	.5	.7
.....	1.6	.....	1.5	1.25	2.95	1.7	1.2	.85	.65	.6	.5	.7
.....	2.3	.....	1.6	1.2	2.45	1.9	1.15	.9	.6	.6	.5	.7
.....	2.6	.....	1.6	1.15	2.15	1.6	1.1	.8	.55	.55	.5	.7
.....	.....	.....	1.65	1.1	2.0	1.45	1.2	.9	.5	.5	.5	.8
.....	.....	.....	1.8	1.1	1.95	1.3	1.3	.8	.5	.5	.45	1.15
.....	.....	.....	1.85	1.3	2.3	1.2	1.2	.75	.5	.45	.45	1.1
.....	.....	.....	1.8	2.5	1.95	1.15	1.1	.7	.5	.4	.45	1.3
.....	.....	.....	1.75	4.3	1.7	1.1	1.1	.6	.5	.4	.45	2.25
.....	.....	.....	1.7	3.85	1.7	1.6	1.25	.55	.45	.4	.45	1.2
.....	.....	.....	1.7	.....	1.55	.....	1.1	.6	.....	.4	.....	1.1

[a] Backwater from ice December 16, 1903. [b] Backwater from ice during part of December, 1904.

Daily gage height, in feet, of Shenanaoah River at Millville, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.[a]												
1	0.9	1.5	0.7	2.0	3.0	4.7	3.5	1.8	2.8	3.7	0.95	1.1
2	.9	1.6	.7	1.95	2.8	4.2	2.7	1.6	3.3	2.8	.95	1.1
3	.9	1.1	.7	2.5	2.7	3.7	2.4	1.5	3.0	2.4	.9	1.5
4	.95	1.0	.75	4.7	2.5	3.35	2.2	1.45	2.8	2.1	.9	1.5
5	.7	1.2	.75	5.7	2.4	3.3	1.15	1.4	2.3	1.8	.9	1.7
6	.9	2.3	.75	4.6	2.3	3.6	2.0	1.7	2.0	1.7	.9	1.8
7	.7	1.6	.8	4.2	2.2	4.1	2.5	2.1	1.9	1.5	.85	1.9
8	.8	1.6	.7	4.15	2.1	4.9	2.6	5.1	1.8	1.5	.85	1.9
9	.7	1.2	.8	3.6	2.1	4.5	2.0	3.8	1.6	1.5	.85	1.7
10	.8	1.2	.8	3.2	5.5	3.7	1.9	2.7	1.5	1.4	.85	1.7
11	.9	1.2	1.7	2.85	3.25	3.1	1.8	2.2	1.45	1.4	.85	1.7
12	2.1	.9	7.3	2.6	4.2	2.8	1.85	2.3	1.5	1.35	.85	1.7
13	2.3	1.2	5.3	2.4	3.5	2.6	2.1	3.1	1.9	1.35	.85	2.0
14	3.5	1.3	3.9	3.0	3.0	3.5	3.0	3.4	1.6	1.4	.8	2.0
15	2.9	1.3	3.2	10.25	2.7	2.9	4.3	2.6	1.5	1.35	.8	7.3
16	2.4	1.5	2.75	9.6	2.5	5.8	5.8	2.2	1.6	1.3	.8	10.5
17	2.1	1.0	2.4	6.1	2.3	10.1	5.2	2.75	1.5	1.2	.8	6.2
18	1.9	.9	2.2	4.9	2.25	5.7	4.2	2.6	1.5	1.1	.8	4.7
19	1.8	.8	2.0	4.8	2.2	4.6	4.3	2.6	1.45	1.1	.8	3.8
20	1.4	.8	1.8	4.6	2.15	3.9	3.9	2.6	1.4	1.1	.8	3.2
21	1.4	.8	2.0	10.55	2.0	3.5	3.5	2.2	1.3	1.0	.8	2.8
22	1.5	.9	2.2	(b)	2.5	5.7	3.2	2.1	1.25	1.0	.8	1.9
23	1.4	.9	2.4	8.5	11.1	5.5	2.7	2.0	1.2	1.0	1.0	1.7
24	1.3	.8	2.55	6.5	8.4	3.8	2.4	1.9	1.2	1.1	2.4	2.5
25	1.3	.9	2.3	5.3	6.3	3.2	2.2	2.2	1.15	1.0	2.7	2.4
26	1.3	.6	2.1	4.8	6.0	2.9	2.0	2.1	1.15	1.0	2.3	1.8
27	1.3	.8	2.1	4.3	6.7	2.9	2.1	2.2	1.1	1.0	1.8	2.3
28	1.3	.8	2.1	3.9	6.2	3.1	1.85	2.5	1.1	1.0	1.7	2.7
29	1.5	.....	2.6	3.5	6.3	2.7	1.8	2.6	1.3	1.0	1.5	4.0
30	1.4	.....	2.4	3.2	5.6	3.0	1.8	2.3	5.3	1.0	1.3	10.5
31	1.2	.....	2.15	.....	4.9	.....	1.85	3.0	.....	1.0	.....	9.
1902.[c]												
1	7.4	3.1	14.5	3.75	2.2	1.45	1.3	.9	.65	.9	.8	2.
2	5.3	2.85	9.0	3.4	2.15	1.4	1.2	1.5	.65	.85	.8	3.
3	4.5	3.0	7.2	3.2	2.2	1.35	1.15	1.9	.6	.8	.8	3.
4	4.0	3.0	5.7	3.1	2.25	1.3	1.1	1.7	.6	.7	.8	4.
5	3.5	2.8	5.0	2.9	2.1	1.3	1.05	1.3	.6	.9	.75	
6	3.25	2.5	4.5	2.8	2.05	1.3	1.1	1.2	.65	1.0	.75	
7	3.0	2.8	4.2	2.6	2.0	1.4	1.1	1.1	.6	.8	.7	
8	2.85	2.7	4.2	2.8	4.0	1.25	1.05	1.05	.55	.75	.7	
9	2.75	2.2	5.5	6.0	2.7	1.2	1.05	1.0	.6	1.1	.7	
10	2.6	2.2	7.8	6.9	2.4	1.2	1.0	.9	.55	1.0	.65	
11	2.5	2.1	8.0	7.2	2.1	1.15	.95	.8	.55	.9	.65	
12	2.4	2.2	7.4	6.2	2.0	1.1	.9	.8	.55	1.0	.6	
13	2.25	2.1	7.2	5.6	2.0	1.1	.9	.8	.5	1.2	.65	
14	2.4	2.0	7.0	5.0	1.95	1.0	.9	.8	.5	1.75	.7	
15	2.2	2.1	6.0	4.4	1.9	1.1	.8	.8	.55	1.55	.65	
16	2.1	1.5	5.0	3.9	1.8	1.2	.8	.75	.55	1.3	.6	
17	2.0	1.9	5.2	3.6	1.7	1.2	.8	.7	.5	1.15	.65	
18	1.9	2.0	5.9	3.4	1.7	1.1	.8	.7	.5	1.0	.8	
19	1.85	2.0	5.0	3.2	1.75	1.6	.75	.85	.5	.95	.8	
20	1.8	1.7	4.4	3.0	1.8	1.4	.75	.8	.55	.9	.9	
21	1.9	1.0	4.1	2.8	1.75	1.2	.8	.8	.6	.85	.8	
22	3.2	2.4	3.8	2.7	1.7	1.2	.8	.8	.6	.8	.9	
23	3.4	4.5	3.5	2.6	1.65	1.1	.8	.8	.6	.75	1.0	
24	2.9	3.9	3.2	2.5	1.6	1.1	.75	.8	.55	.7	1.0	
25	2.5	4.7	3.1	2.4	1.6	1.2	.75	.75	.55	.7	1.0	
26	2.3	(d)	2.95	2.3	1.6	1.2	.8	.75	.6	.7	1.2	
27	2.5	(d)	2.8	2.25	2.2	1.15	1.0	.7	.6	.65	2.0	
28	3.6	11.0	2.75	2.2	1.75	1.1	.9	.7	.6	.9	2.5	
29	4.4	.....	3.0	2.2	1.6	1.3	1.3	.7	.65	.85	2.4	
30	3.6	.....	3.8	2.2	1.55	1.4	1.3	.65	1.0	.8	2.1	
31	3.3	.....	3.9	.....	1.5	.....	1.4	.65	.....	.8	.....	

[a] Water backed by ice during part of January and February, 1901.
[b] No reading: river out of banks April 22 and December 31, 1901.
[c] Ice conditions during part of February, 1902.
[d] Flood; no observation February 26–27, 1902.

gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
....	1.7	4.0	7.2	6.4	2.5	4.4	4.6	1.3	1.2	1.1	0.9	0.7
....	1.7	3.6	6.5	5.0	2.4	3.8	4.2	1.35	2.2	1.1	.9	.7
....	6.1	3.3	5.0	4.4	2.3	3.2	3.0	1.3	2.7	1.1	.9	.7
....	8.7	3.3	4.2	4.1	2.2	2.5	2.75	1.5	2.05	1.05	.9	.65
....	5.9	3.8	3.8	3.9	2.15	2.2	2.5	1.6	1.7	1.05	.95	.6
....	4.75	4.2	3.5	3.7	2.1	2.0	3.4	1.9	1.55	1.0	1.0	.6
....	4.0	3.7	3.25	3.5	2.1	3.9	4.65	2.0	1.45	1.0	.9	.6
....	3.5	3.3	3.2	3.3	2.05	9.2	3.7	1.7	1.3	1.8	.9	.55
....	3.1	2.7	3.6	3.3	2.0	6.5	2.3	1.5	1.25	2.1	.9	.6
....	2.8	2.5	3.4	3.3	1.9	8.9	2.0	1.55	1.2	2.0	.9	.8
....	2.7	2.3	3.3	3.2	1.85	4.9	1.95	1.4	1.2	1.8	.9	.7
....	2.7	2.1	3.2	3.0	1.8	4.6	1.9	1.4	1.3	1.65	.9	.7
....	2.2	2.3	3.2	3.1	1.75	4.0	2.7	1.35	1.2	1.55	.9	.7
....	2.3	2.7	3.0	5.4	1.7	4.3	2.6	1.3	1.2	1.5	.85	.8
....	2.0	2.6	2.95	7.8	1.7	3.6	2.8	1.3	1.2	1.4	.85	.8
....	2.3	2.6	2.8	6.6	1.65	3.1	2.7	1.25	1.1	1.3	.85	[a]1.1
....	2.2	3.3	2.7	6.1	1.65	2.8	2.2	1.25	1.3	1.3	.9	.5
....	2.35	4.6	2.6	5.0	1.6	2.6	2.0	1.2	2.1	1.25	.9	.7
....	2.3	4.1	2.55	4.4	1.55	2.4	1.9	1.5	4.6	1.2	.85	.8
....	1.95	3.6	2.5	3.9	1.55	2.1	1.8	1.45	3.1	1.2	.85	.9
....	2.2	3.4	2.5	3.7	1.5	2.0	1.7	1.3	2.7	1.2	.85	1.1
....	3.5	3.3	2.5	3.6	1.5	2.0	1.65	1.25	2.2	1.15	.85	1.0
....	6.0	3.0	4.1	3.3	1.5	1.9	1.6	1.2	1.8	1.1	.8	1.2
....	3.4	3.0	7.3	3.1	1.5	1.9	1.55	1.1	1.6	1.05	.8	1.4
....	2.8	3.2	7.6	3.0	1.5	1.85	1.5	1.05	1.5	1.0	.8	1.2
....	2.6	3.5	5.7	2.9	1.8	1.8	1.5	1.0	1.4	1.0	.8	.8
....	2.3	3.5	4.3	2.8	1.8	2.65	1.45	.95	1.3	1.0	.75	.9
....	3.35	4.0	3.8	2.7	1.7	3.2	1.35	1.1	1.25	.95	.7	1.0
....	6.9	.....	3.4	2.65	1.7	5.2	1.3	1.8	1.2	.95	.6	.9
....	5.2	.....	3.4	2.55	1.85	5.7	1.25	1.25	1.15	.95	.6	.8
....	4.5	.....	5.5	.....	2.05	.....	1.25	1.2	.....	.95	.....	.8
....	.8	.....	.....	1.8	3.3	4.0	1.5	1.15	.6	.45	.45	.45
....	.85	.....	.....	1.8	3.3	2.6	1.4	1.05	.6	.4	.45	.45
....	1.2	.....	.....	1.75	2.7	2.3	1.3	1.1	.6	.4	.4	.5
....	1.2	.....	.....	1.7	2.4	2.1	1.2	1.25	.6	.4	.5	.5
....	1.0	.....	.....	1.6	2.15	2.6	1.1	1.4	.6	.4	.45	.5
....	1.0	.....	.....	1.5	2.1	2.85	1.2	1.4	.6	.4	.45	.55
....	1.1	.....	.....	1.5	1.95	4.0	1.15	1.7	.6	.45	.45	.5
....	1.1	.....	2.3	1.5	2.0	2.9	1.3	1.8	.6	.45	.45	.5
....	1.3	.....	4.9	1.6	2.0	2.4	1.25	1.45	.55	.4	.4	.5
....	1.2	.....	3.5	1.7	2.3	2.15	1.35	1.4	.55	.4	.4	.5
....	1.2	.....	3.0	2.45	2.5	2.0	5.6	1.35	.5	.4	.5	.85
....	1.1	.....	2.5	2.4	2.45	1.85	3.7	1.4	.5	.5	.45	.5
....	1.1	.....	2.3	2.2	2.3	1.75	2.8	1.35	.6	.5	.5	.65
....	1.0	.....	2.0	2.0	2.05	1.5	2.1	1.3	.6	.55	.6	.65
....	1.0	.....	1.9	1.75	1.9	1.4	1.75	1.1	.9	.5	.6	.75
....	1.0	.....	1.8	1.65	1.85	1.35	1.5	1.05	.9	.5	.5	.6
....	1.0	.....	1.75	1.6	1.8	1.4	1.4	1.0	.8	.5	.5	1.65
....	1.0	.....	1.7	1.55	1.8	1.65	1.3	1.0	.75	.5	.5	1.8
....	1.1	.....	1.6	1.45	1.9	1.4	1.3	.95	.7	.5	.55	1.55
....	1.1	.....	1.5	1.45	2.3	1.35	1.2	.9	.65	.45	.5	.8
....	1.3	.....	1.45	1.3	3.5	1.6	1.2	.9	.6	.6	.5	.7
....	1.6	.....	1.5	1.25	2.95	1.7	1.2	.85	.65	.6	.5	.7
....	2.3	.....	1.6	1.2	2.45	1.9	1.15	.9	.6	.6	.5	.7
....	2.6	.....	1.6	1.15	2.15	1.6	1.1	.8	.55	.55	.5	.7
....	.....	.....	1.65	1.1	2.0	1.45	1.2	.9	.5	.5	.5	.8
....	.....	.....	1.8	1.1	1.95	1.3	1.3	.8	.5	.5	.45	1.15
....	.....	.....	1.85	1.3	2.3	1.2	1.2	.75	.5	.45	.45	1.1
....	.....	.....	1.8	2.5	1.95	1.15	1.1	.7	.5	.4	.45	1.3
....	.....	.....	1.75	4.3	1.7	1.1	1.1	.6	.5	.4	.45	2.25
....	.....	.....	1.7	3.85	1.7	1.6	1.25	.55	.45	.4	.45	1.2
....	.....	.....	1.7	.....	1.55	.....	1.1	.6	.....	.4	.....	1.1

[a] Backwater from ice December 16, 1903. [b] Backwater from ice during part of December, 1904.

Daily gage height, in feet, of Shenandoah River at Millville, W. Va.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1	1.0	1.4	3.35	2.2	1.2	1.2	1.9	2.1	1.15	0.6	0.7	0.6
2	.95	1.2	2.75	2.05	1.15	1.2	1.75	1.7	1.0	.55	.7	.6
3	.85	1.3	2.7	1.9	1.15	1.5	1.75	1.4	.95	.5	.65	.6
4	1.4	1.3	2.8	1.8	1.1	1.2	1.6	1.3	.9	.5	.65	.6
5	1.6	1.2	2.8	1.8	1.1	1.1	1.6	1.2	1.0	.5	.65	.6
6	1.55	1.2	[a]4.1	2.0	1.0	1.0	1.6	1.1	1.05	.5	.65	.8
7	2.1	1.2	2.5	2.45	1.0	1.15	2.3	1.1	1.0	.5	.65	1.3
8	2.8	1.25	2.5	2.45	1.0	2.0	2.1	1.1	1.0	.5	.65	1.2
9	2.5	1.25	2.8	2.3	.95	1.2	2.3	1.1	.95	.5	.65	1.1
10	2.0	1.3	3.7	2.1	.95	1.0	2.1	1.05	.8	.5	.65	1.0
11	1.8	1.35	4.75	2.0	1.0	1.0	1.9	1.05	.8	.5	.6	.8
12	1.5	1.45	4.3	1.95	1.0	1.1	2.0	1.0	.85	.55	.6	.8
13	2.0	1.4	3.3	1.9	1.0	.9	2.8	.95	.8	.7	.6	.8
14	2.6	1.25	3.2	1.8	.95	.8	2.6	.95	.8	.7	.6	.8
15	2.9	1.25	2.9	1.7	2.0	.8	3.8	1.1	.8	.7	.6	.8
16	2.5	1.3	2.6	1.7	2.0	.75	5.3	1.1	.75	.7	.6	.8
17	2.0	1.55	2.4	1.65	2.1	.75	3.3	3.2	.8	.65	.6	.8
18	2.0	1.55	2.3	1.6	2.3	.7	2.7	2.3	.8	.65	.6	.8
19	2.0	1.5	2.2	1.5	2.1	.7	2.3	1.9	.85	.65	.55	.9
20	1.7	1.6	2.1	1.45	1.8	.7	2.0	1.5	.8	.65	.55	.9
21	1.6	1.55	2.4	1.4	1.7	.9	1.8	1.4	.8	.6	.6	2.0
22	1.5	1.5	2.7	1.4	1.5	3.3	1.8	1.3	.8	.6	.6	4.1
23	1.4	1.55	4.0	1.4	1.4	3.2	1.8	1.2	.8	.6	.6	5.3
24	1.3	1.6	3.4	1.35	1.3	3.5	2.8	1.1	.8	.6	.6	4.3
25	1.6	2.0	3.2	1.3	1.3	5.9	2.4	1.1	.75	.6	.6	3.6
26	1.6	2.2	3.6	1.2	1.2	4.8	2.2	1.9	.6	.65	.6	3.3
27	1.85	2.6	3.2	1.2	.9	3.5	1.9	2.1	.6	.8	.6	2.8
28	1.6	3.0	2.9	1.2	1.0	3.0	1.6	1.8	.6	.9	.6	2.4
29	1.5	.....	2.7	1.3	1.0	2.5	1.4	1.5	.55	.85	.6	2.2
30	1.6	.....	2.5	1.3	1.0	2.1	1.9	1.25	.55	.85	.6	2.3
31	1.5	.....	2.3	.....	1.1	.....	2.4	1.1	.....	.85	.....	2.1
1906.												
1	2.7	2.3	1.1	4.75	2.3	1.5	2.0	1.3	3.55	1.45	2.7	1.8
2	2.45	2.2	1.1	4.2	2.2	1.5	1.8	1.4	3.8	1.45	2.5	1.8
3	2.25	2.0	1.2	3.8	2.1	1.4	1.6	1.8	2.7	1.4	2.4	1.5
4	3.4	[b]2.4	2.2	3.4	2.0	1.3	1.3	1.4	2.2	1.7	2.3	1.7
5	5.3	2.0	2.5	3.1	1.95	1.2	2.15	2.5	2.2	2.5	2.2	1.6
6	4.5	1.95	3.5	2.9	1.9	2.1	1.7	2.3	2.0	3.5	2.1	1.7
7	3.6	1.9	2.9	2.7	1.85	1.3	1.55	2.1	1.9	3.1	2.05	1.6
8	3.0	1.8	2.5	2.6	1.8	1.2	1.6	2.0	1.8	2.6	2.0	1.6
9	2.7	1.6	2.3	2.4	2.1	1.2	1.5	2.2	1.65	2.3	1.9	1.5
10	2.45	1.6	2.1	2.45	2.05	1.65	1.35	2.3	1.6	2.05	1.85	1.3
11	2.3	1.75	2.0	2.6	1.9	1.9	1.3	2.0	1.5	1.8	1.8	1.4
12	2.15	1.5	1.9	2.6	1.85	1.5	1.3	2.0	1.5	1.8	1.8	1.6
13	2.0	1.45	1.75	2.45	1.8	1.2	1.3	3.0	1.45	1.65	1.75	1.5
14	2.0	1.3	1.7	2.3	1.7	1.2	1.3	3.4	1.9	1.5	1.75	1.5
15	2.0	1.35	1.7	3.2	1.6	1.2	1.4	3.8	1.6	1.4	1.75	1.4
16	2.2	1.3	1.8	4.7	1.55	2.0	1.3	3.9	1.5	1.4	1.7	1.6
17	2.3	1.3	1.9	4.2	1.4	2.6	1.3	3.2	1.35	1.4	1.65	1.7
18	2.25	1.2	2.6	3.6	1.35	2.1	1.3	4.1	1.3	1.5	1.6	4.2
19	2.2	1.2	2.7	3.2	1.45	3.8	1.4	3.35	1.35	4.1	1.8	4.5
20	2.1	1.2	2.7	2.95	1.4	2.4	1.5	4.2	1.3	11.3	2.25	4.0
21	2.0	1.2	2.7	2.7	1.3	2.7	1.4	3.9	1.25	12.8	4.3	3.5
22	1.9	1.2	2.9	2.5	1.25	4.8	1.3	3.4	1.2	8.3	3.8	3.0
23	1.8	1.2	3.15	2.4	1.2	3.7	1.2	3.3	1.2	6.5	3.85	3.1
24	1.8	1.2	3.1	2.25	1.2	2.9	2.0	4.0	1.2	5.7	2.9	3.0
25	3.8	1.15	2.9	2.1	1.15	2.5	1.6	4.5	1.1	4.9	2.7	2.8
26	3.2	1.1	2.9	2.0	1.1	2.15	1.5	4.5	1.25	4.2	2.7	2.7
27	2.7	1.1	3.0	2.0	1.2	2.4	1.4	3.8	1.25	3.8	2.25	2.6
28	2.5	1.1	4.8	3.4	1.3	3.5	1.4	5.4	1.25	3.5	2.15	2.4
29	2.4	.....	4.9	2.9	1.5	3.25	1.4	4.7	1.25	3.2	2.1	2.4
30	2.4	.....	4.6	2.5	1.4	2.4	1.5	5.0	1.35	3.0	2.0	2.3
31	2.5	.....	4.6	.....	1.4	.....	1.3	4.2	.....	2.8	.....	2.2

[a] Backwater March 6, 1905.

[b] Backwater from ice February 4, 1906.

Rating tables for Shenandoah River at Millville, W. Va.

ɪIL 15, 1895, TO FEBRUARY 6, 1897, AND MARCH 8, 1904, TO DECEMBER 31, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
0.30	430	2.30	2,940	4.60	8,860	8.40	26,400
.40	480	2.40	3,130	4.80	9,540	8.60	27,700
.50	540	2.50	3,330	5.00	10,260	8.80	29,000
.60	610	2.60	3,530	5.20	11,020	9.00	30,400
.70	690	2.70	3,730	5.40	11,780	9.20	31,800
.80	780	2.80	3,940	5.60	12,580	9.40	33,200
.90	880	2.90	4,150	5.80	13,400	9.60	34,600
1.00	980	3.00	4,370	6.00	14,240	9.80	36,000
1.10	1,090	3.10	4,600	6.20	15,120	10.00	37,500
1.20	1,200	3.20	4,840	6.40	16,000	11.00	45,100
1.30	1,320	3.30	5,080	6.60	16,920	12.00	53,500
1.40	1,450	3.40	5,320	6.80	17,840	13.00	62,700
1.50	1,580	3.50	5,570	7.00	18,800	14.00	72,700
1.60	1,720	3.60	5,830	7.20	19,780	15.00	83,200
1.70	1,870	3.70	6,100	7.40	20,780	16.00	94,300
1.80	2,030	3.80	6,380	7.60	21,820	17.00	105,900
1.90	2,200	3.90	6,670	7.80	22,880	18.00	118,000
2.00	2,380	4.00	6,960	8.00	24,020	19.00	130,600
2.10	2,560	4.20	7,560	8.20	25,200	20.00	143,700
2.20	2,750	4.40	8,200				

FEBRUARY 10, 1897, TO JANUARY 24, 1904.[b]

0.20	470	2.10	2,770	4.00	7,380	6.80	18,300
.30	520	2.20	2,960	4.10	7,700	7.00	19,220
.40	580	2.30	3,150	4.20	8,020	7.20	20,140
.50	650	2.40	3,350	4.30	8,340	7.40	21,100
.60	730	2.50	3,560	4.40	8,680	7.60	22,060
.70	820	2.60	3,770	4.50	9,020	7.80	23,060
.80	910	2.70	3,990	4.60	9,360	8.00	24,060
.90	1,010	2.80	4,210	4.70	9,700	8.20	25,100
1.00	1,120	2.90	4,440	4.80	10,060	8.40	26,200
1.10	1,230	3.00	4,670	4.90	10,420	8.60	27,300
1.20	1,350	3.10	4,910	5.00	10,800	8.80	28,500
1.30	1,480	3.20	5,150	5.20	11,560	9.00	29,800
1.40	1,620	3.30	5,400	5.40	12,320	9.20	31,200
1.50	1,700	3.40	5,650	5.60	13,120	9.40	32,700
1.60	1,910	3.50	5,910	5.80	13,940	9.60	34,200
1.70	2,070	3.60	6,180	6.00	14,780	9.80	35,800
1.80	2,240	3.70	6,460	6.20	15,640	10.00	37,500
1.90	2,410	3.80	6,760	6.40	16,520		
2.00	2,590	3.90	7,060	6.60	17,400		

[a] is table is strictly applicable only for open-channel conditions. It is based on 14 discharge measurnts made during 1895 and 1904. It is well defined between gage heights 0.4 feet and 5.2 feet. Estiabove 5.0 feet are based on a discharge curve which is the product of a well-defined area curve fairly accurate extension of the velocity curve. The discharge curves 1895–1906 are the same above eight 10.0 feet.

[b] s table is strictly applicable only for open-channel conditions. It is based on 14 discharge measmade during 1897–1903. It is well defined between gage heights 0.5 foot and 5.0 feet. The rge curves 1895–1906 are the same above gage height, 10.0 feet.

Estimated monthly discharge of Shenandoah River at Millville, W. Va.

[Drainage area, 3,000 square miles.[a]]

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss, in inches.
1895.								
January							5.54	
February							1.34	
March							2.73	
April 15-30	4,600	1,870	2,904	0.970	0.576		[b]3.78	
May	20,780	2,560	5,570	1.86	2.14	65	3.28	1.14
June	3,130	980	1,613	.539	.601	14	4.14	3.54
July	7,260	980	1,880	.628	.724	16	4.44	3.72
August	1,580	540	806	.269	.310	17	1.82	1.51
September	1,320	610	722	.241	.269	41	.66	.39
October	610	490	537	.179	.206	20	1.06	.85
November	690	540	621	.207	.231	15	1.57	1.34
December	1,450	610	754	.252	.290	9	3.09	2.80
The year							33.45	
1896.								
January	11,400	880	2,434	.813	.937	38	2.49	1.55
February	12,580	1,450	3,709	1.24	1.34	35	3.78	2.44
March	12,180	1,450	3,842	1.28	1.48	35	4.25	2.77
April	8,860	1,450	2,807	.937	1.05	85	1.24	.19
May	4,370	1,090	2,127	.710	.819	36	2.28	1.46
June	3,940	780	2,056	.686	.765	13	5.71	4.95
July	9,030	1,320	2,858	.954	1.10	18	6.21	5.11
August	1,870	780	1,150	.384	.443	14	3.20	2.76
September	13,190	540	1,042	.348	.388	5	7.22	6.83
October [c]	139,700	880	7,768	2.59	2.99	623	.48	−2.51
November	4,840	880	1,835	.613	.684	16	4.16	3.48
December	6,380	1,450	2,296	.767	.884	383	.23	−.65
The year	139,700	540	2,827	.944	12.88	31	41.25	28.37
1897.								
January [d]	1,720	980	1,220	.407	.469	33	4.41	.94
February (25 days)	37,870	1,090	11,680	3.90	3.63		[e]6.28	
March	6,760	2,590	4,946	1.65	1.90	81	2.34	.44
April	3,350	1,620	2,671	.892	.995	53	1.90	.90
May	30,620	1,760	6,243	2.08	2.40	47	5.13	2.73
June	2,410	1,010	1,632	.545	.608	19	3.18	2.57
July [f]	3,770	910	1,426	.476	.549	13	4.14	3.59
August	1,760	730	987	.330	.380	27	1.41	1.03
September	1,350	580	664	.222	.248	25	1.01	.76
October	1,010	550	692	.231	.266	10	2.59	2.32
November	1,620	650	859	.287	.320	12	2.59	2.27
December [d]	3,990	820	1,619	.541	.624	18	3.51	2.89
The year							35.49	
1898.								
January	6,180	1,010	2,435	.813	.937	31	3.05	2.11
February [g]	2,770	1,010	1,612	.538	.560	75	.75	.19
March	5,650	1,010	2,227	.744	.858	23	3.73	2.87
April	13,120	2,070	4,353	1.45	1.62	61	2.66	1.04
May	29,150	2,070	5,711	1.91	2.20	42	5.21	3.01
June	2,410	1,120	1,647	.550	.614	21	2.86	2.25
July [h]	3,770	820	1,249	.417	.481	11	4.18	3.70
August [i]	50,900	1,350	8,164	2.73	3.15	41	7.73	4.58
September	1,835	1,120	1,360	.454	.506	26	1.97	1.46
October	30,500	1,010	5,684	1.90	2.19	31	7.10	4.91
November	4,210	2,070	2,827	.944	1.05	59	1.79	.74
December	14,780	2,410	4,498	1.50	1.73	55	3.13	1.40
The year	50,900	820	3,481	1.16	15.90	36	44.16	28.26

[a] 3,000 square miles used to obtain run-off for 1906; 2,995 used for all other years.
[b] Precipitation for complete month, April, 1895.
[c] Estimates October 1-2, 1896, approximate.
[d] Ice conditions during January and December 24-31, 1897. No correction made in estimates.
[e] Precipitation for whole month, February, 1897.
[f] Estimate July 11, 1897, interpolated.
[g] Ice conditions during February, 1898. No correction made in estimates.
[h] Estimate July 2, 1898, interpolated.
[i] Gage height August 11, 1898, estimated. Discharge approximate.

d monthly discharge of Shenandoah River at Millville, W. Va.—Continued.

	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss of, in inches.
.....	17,840	2,770	5,116	1.71	1.97	78	2.52	0.55
1 a b ..	7,380	2,070	3,675	1.23	.960	.....	c 4.95	.....
.....	12,720	4,440	7,065	2.36	1.93	.....	c 5.12	.....
.....	4,910	2,070	3,289	1.10	1.23	106	1.16	— .07
.....	4,910	1,480	2,533	.846	.975	20	4.95	3.97
.....	4,670	1,010	1,607	.537	.599	29	2.09	1.49
.....	1,760	730	877	.293	.338	14	2.51	2.17
.....	1,910	650	992	.331	.382	10	3.94	3.56
.....	1,760	730	989	.330	.368	10	3.78	3.41
.....	910	650	785	.262	.302	13	2.34	2.04
.....	5,150	910	1,403	.468	.522	64	.81	.29
.....	4,440	820	1,398	.467	.538	40	1.34	.80
ir....	.....	.....	.....	.....	.....	.....	35.51	.....
.....	14,780	1,230	2,970	.992	1.14	44	2.57	1.43
.....	14,360	1,350	3,833	1.28	1.33	36	3.73	2.40
.....	16,960	2,590	5,866	1.96	2.26	61	3.72	1.46
.....	4,670	1,835	2,803	.936	1.04	55	1.89	.85
.....	2,410	1,230	1,689	.564	.650	27	2.42	1.77
.....	9,020	1,010	2,249	.751	.838	14	5.98	5.14
.....	4,210	775	1,374	.459	.529	14	3.76	3.23
.....	1,290	690	829	.277	.319	17	1.93	1.61
.....	1,230	580	696	.232	.259	8	3.14	2.88
.....	2,770	650	947	.316	.364	11	3.19	2.83
.....	9,020	730	1,453	.485	.541	18	2.94	2.40
.....	10,060	1,010	2,232	.745	.859	47	1.83	.97
ir....	16,960	580	2,245	.750	10.13	27	37.10	26.97
.....	5,910	820	1,812	.605	.698	30	2.31	1.61
.....	3,150	730	1,315	.439	.457	139	.33	— .13
.....	20,620	820	3,376	1.13	1.30	34	3.80	2.50
.....	50,000	2,500	12,840	4.29	4.79	77	6.24	1.45
.....	45,920	2,590	8,704	2.91	3.36	58	5.82	2.46
.....	38,240	3,770	8,225	2.75	3.07	41	7.54	4.47
.....	13,940	1,290	4,437	1.48	1.71	39	4.38	2.67
.....	11,180	1,620	3,528	1.18	1.36	23	5.92	4.56
.....	11,940	1,230	2,496	.833	.929	25	3.78	2.85
.....	6,460	1,120	1,709	.591	.681	99	.69	.01
.....	3,990	910	1,341	.448	.500	25	2.01	1.51
.....	50,000	1,350	8,124	2.71	3.12	51	6.12	3.00
ar....	50,000	730	4,831	1.61	21.98	45	48.94	26.96
.....	21,100	2,240	5,176	1.73	1.99	74	2.69	.70
.....	50,000	1,120	8,611	2.88	3.00	67	4.46	1.46
.....	77,900	4,100	13,880	4.63	5.34	148	3.61	—1.73
.....	20,140	2,960	6,785	2.27	2.53	113	2.23	— .30
.....	7,380	1,760	2,606	.870	1.00	38	2.64	1.64
.....	1,910	1,120	1,402	.468	.522	18	2.93	2.41
.....	1,620	865	1,097	.366	.422	19	2.17	1.75
.....	2,410	775	1,002	.355	.409	18	2.22	1.81
.....	1,120	650	724	.242	.270	10	2.59	2.32
.....	2,155	775	1,069	.357	.412	11	3.65	3.24
.....	3,560	730	1,157	.386	.431	13	3.21	2.78
.....	9,020	2,240	4,728	1.58	1.82	54	3.38	1.56
year..	77,900	650	4,025	1.34	18.15	51	35.78	17.63

tions during January and February, 1899. No correction made in estimates.
s February 12-13, 1899, interpolated.
tion for complete months, February and March, 1899.
er from ice February 5-6, 1900. Discharge corrected.
ckwater from ice during part of January and February, 1901; no correction made in esti-

nd December 31, 1901, river out of banks, discharge estimated 50,000 second-feet.
tions during part of February 1902; no correction made in estimates. February 26-27, 1902,
banks; discharge estimated 50,000 second-feet.

Estimated monthly discharge of Shenandoah River at Millville, W. Va.—Continued.

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss, in inches.
1903.								
January	27,900	2,070	6,802	2.27	2.62	64	4.08	1.46
February	9,360	2,770	5,448	1.82	1.90	54	3.49	1.59
March	22,060	3,560	7,907	2.64	3.04	73	4.15	1.11
April	23,060	3,665	7,880	2.63	2.93	81	3.62	.69
May	3,560	1,760	2,321	.775	.894	33	2.69	1.80
June	31,200	2,240	7,448	2.49	2.78	36	7.63	4.85
July	9,530	1,415	3,453	1.15	1.33	43	3.06	1.73
August	2,590	1,065	1,590	.531	.612	17	3.53	2.92
September	9,360	1,230	2,249	.751	.838	35	2.42	1.58
October	2,770	1,065	1,454	.485	.559	23	2.39	1.83
November	1,120	730	961	.321	.358	44	.82	.46
December[a]	1,620	650	927	.310	.357	38	.96	.60
The year	31,200	650	4,037	1.35	18.22	47	38.84	20.62
1904.								
January 1 to 24	3,770	910	1,428	.477	.426		[b] 1.80	
February							1.26	
March 8 to 31	9,900	1,515	2,546	.850	.759		[b] 2.08	
April	7,880	1,090	2,191	.732	.817	31	2.64	1.82
May	5,570	1,650	2,779	.928	1.07	31	3.43	2.36
June	6,960	1,090	2,430	.811	.905	16	5.57	4.67
July	12,580	1,090	1,930	.644	.742	15	5.04	4.30
August	2,030	575	1,096	.366	.422	17	2.53	2.11
September	880	510	620	.207	.231	12	1.95	1.72
October	610	480	521	.174	.201	17	1.20	1.00
November	610	480	528	.176	.196	21	.95	.75
December[c]	2,845	510	.780	.260	.300	12	2.46	2.16
The year							30.91	
1905.								
January	4,150	830	2,065	.689	.794	28	2.86	2.06
February	4,370	1,200	1,684	.562	.585	27	2.14	1.56
March[d]	9,370	2,560	4,387	1.46	1.68	69	2.44	.76
April	3,230	1,200	1,945	.649	.724	38	1.90	1.18
May	2,940	880	1,382	.461	.531	14	3.93	3.40
June	13,820	680	2,552	.852	.950	17	5.50	4.55
July	11,400	1,450	2,994	1.00	1.15	19	5.98	4.83
August	4,840	930	1,557	.520	.600	19	3.19	2.59
September	1,145	575	810	.270	.301	18	1.65	1.35
October	880	540	640	.214	.247	9	2.84	2.59
November	690	575	624	.208	.232	26	.90	.67
December	11,400	610	2,336	.780	.899	24	3.82	2.92
The year	13,820	540	1,915	.639	8.69	23	37.15	28.46
1906.								
January	11,400	2,030	3,719	1.24	1.43			
February[e]	2,940	1,090	1,643	.548	.571			
March	9,900	1,090	3,888	1.30	1.50			
April	9,370	2,380	4,464	1.49	1.66			
May	2,940	1,090	1,803	.601	.693			
June	9,540	1,200	2,895	.965	1.08			
July	2,655	1,200	1,578	.527	.608			
August	11,780	1,320	5,220	1.74	2.01			
September	6,380	1,090	1,980	.660	.736			
October	60,820	1,450	8,248	2.75	3.17			
November	7,880	1,720	3,021	1.01	1.13			
December	8,520	1,450	3,052	1.02	1.18			
The year	60,820	1,090	3,459	1.15	15.77			

[a] Backwater December 16, 1903, discharge corrected.
[b] Precipitation for complete months, January and March, 1904.
[c] Backwater during part of December, 1904, discharge corrected.
[d] Backwater March 6, 1905; discharge corrected.
[e] Backwater February 4, 1906; discharge corrected.

The following table gives the horsepower, 80 per cent efficiency per ɔt of fall, that may be developed at different rates of discharge, and ows the number of days on which the flow and the corresponding rsepower were respectively less than the amounts given in the col-ıns for "discharge" and "horsepower."

ischarge and horsepower table for Shenandoah River at Millville, W. Va., for 1895 to 1906.

Discharge in second-feet.	Horsepower, 80 per cent efficiency, per foot fall.	Days of deficient flow.											
		[a] 1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	1906.
495	45	.....	.....	.....	.....	.....	.....	.....	.....	.....	15	.....	.....
550	50	33	4	.....	.....	.....	.....	.....	.....	.....	73	9	.....
660	60	98	24	50	.....	3	20	.....	5	1	106	60	.....
770	70	118	26	67	.....	29	54	1	26	8	114	73	.....
880	80	125	34	85	7	70	89	11	63	19	122	101	.....
990	90	154	75	107	11	112	109	38	97	37	133	137	.....
1,100	100	160	82	146	32	141	128	55	112	59	147	155	7
1,320	120	166	89	179	91	167	161	78	145	82	180	180	36
1,540	140	185	130	210	116	184	202	104	167	118	215	208	85
1,760	160	192	192	220	143	194	219	120	174	129	234	238	116

[a] April 15 to December 31, 1895.

OTE.—The minimum flow during the period covered by the above table was 480 second-feet, giving orsepower per foot of fall, for fifteen days during October and November, 1904.

ISCELLANEOUS DISCHARGE MEASUREMENTS IN SHENANDOAH RIVER BASIN BELOW NORTH AND SOUTH FORKS.

The following miscellaneous discharge measurements have been ıde in the basin of Shenandoah River below the junction of North d South forks.

liscellaneous discharge measurements in Shenandoah River basin below North and South forks.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Feet per sec.*	*Second-feet.*
ıber 7.....	Wappan Run.....	Near mouth near Linden, Va.	5	1.4	0.79	[a] 1.1
ıber 9.....	Stonebridge Run.....	Near Milldale, Va.....	.....	.....	.....	[b] 3
Do.....	Parker Creek.....	Near Millwood, Va.....	.....	.....	.....	4
ıber 8.....	Crystal Run.....	Near Berryville, Va.....	.....	.....	.....	[b] 3
ıber 2.....	Bullskin Run.....	At Johnson's factory, at mouth near Kabletown, W. Va.	8	12	.62	[c] 7.5
ıber 1.....	Evitt Run.....	At bridge near mouth near Charles Town, W. Va.	16	13	.92	12
ıber 25.....	Flowing Run.....	Near Millville, W. Va.....	6	7.2	.63	4.5
1894.						
6.....	Shenandoah River...	Harpers Ferry, W. Va.....	.....	467	2.61	1,218

[a] Low discharge; it may be due to storage of water at dam above.
[b] Stonebridge Run and Crystal Run fed by large springs.
[c] Water considered very low.

POTOMAC RIVER BASIN BELOW SHENANDOAH RIVER.

POTOMAC RIVER AT POINT OF ROCKS, MD.

This station was established by C. C. Babb February 17, 1895. It is located at the steel highway bridge at Point of Rocks, Md.

The channel is straight for 500 feet above and 200 feet below the station. It is 1,300 feet wide, broken by seven bridge piers. Both banks overflow only at extremely high water, and are not wooded. In the two right spans the bed is composed of mud, and is subject to some change; in the other spans the bed is composed of gravel and cobblestones and is permanent. The current does not flow at right angles with the bridge in all of the spans.

Discharge measurements are made from the eight-span steel toll bridge, to which the gage is attached. The initial point for soundings is the left end of the lower guard rail, 0.4 foot beyond the center of the end pin, on the downstream side of the bridge.

As originally placed the gage was located in the third span of the bridge from the left bank. The length of the wire from the end of the weight to the marker was 48.0 feet. The zero of the gage was 40.9 feet below bench mark No. 1, described below. June 18, 1896, a new wire gage was placed on the lower side of the first span of the bridge. The zero of the gage was changed to 41.3 feet below bench mark No. 1, the wire length being 44.19 feet. During 1896 and 1897 the wire became rusted and broke frequently; the changes in wire length were not recorded. January 25, 1898, a new wire was put in, the length being 44.22 feet, and this length has been maintained since that date, the datum elevation continuing at 41.3 feet below bench mark No. 1.

During the period between the measurements of April 16 and July 29, 1901, a large quantity of earth excavated from the canal was thrown into the river along its left bank, changing the section and possibly affecting the flow of the river. The shifting of this material necessitated moving the gage farther from the shore. This was done by the observer, who attempted to install a temporary gage to read the same as the old one. The indications are, however, that the gage was not set to read exactly the same, and the gage heights between April 16, 1901, and September 2, 1902, are somewhat in error.

A standard chain gage was installed at this station September 2, 1902. It is bolted to the hand rail on the lower side of the bridge on the first span from the left bank. The length of the chain is 44.22 feet, the same length as had been previously used. In placing the box, however, the gage datum was lowered 0.45 foot, making elevation of the bench mark above gage datum 41.75 feet, instead of 41.3 feet. The gage is read once each day by George H. Hickman. Bench mark No. 1, established November 16, 1896, is a copper bolt in a large

capstone on the lower wing wall of the north abutment, about 10 feet from the north end of the first iron truss and 41.75 feet above the datum of the gage.

All estimates published in Progress Reports prior to 1905 have been revised. Estimates do not include the discharge of the Chesapeake and Ohio Canal, which forms an appreciable percentage of the total flow of the river at low stages. Uncertain length of gage wire or chain and ice conditions are the chief sources of error at this station. Two rating curves are necessary on account of the change in gage datum made September 2, 1902. For normal conditions of flow and correct wire or chain length the estimates as published below are probably within 5 per cent of the true discharge of the river section.

For the period January 1 to June 17, 1896, when the gage-height records are in doubt, a comparison of the Point of Rocks estimates was made with the Cumberland, Springfield, and Millville estimates. This comparison seems to indicate that the Point of Rocks estimates for this period may be as much as 20 per cent too low.

During 1897 the gage-wire length was greatly in error. The proper correction to be applied to the gage heights was determined by the amount that the discharge measurements of that year plotted above or below the rating curve. A comparison of the Point of Rocks estimates with the Cumberland and Millville estimates indicates that the former are well within 10 per cent of the true discharge for 1897.

It is believed that estimates from April 16 to December 31, 1901, can be considered within 10 per cent of the correct discharge. Although the difference between the gage zero and the datum plane was not known with certainty, it is believed to have been very small, because the measurements for that period plot on the first rating curve, and because the hydrographer's and the observer's gage-height observations on the dates of the measurements agree.

It is believed that the second rating curve, which is applied after March 31, 1902, gives estimates correctly within 10 per cent from June 22 to September 1, 1902, because the measurement of June 22 plots on this rating curve and the gage height agrees with the observer's gage height. There are no data available, however, for determining the exact date on which the change should be made from the first to the second rating curve. The date was arbitrarily chosen as April 1, 1902, which is about halfway between the measurements of December 27, 1901, and June 22, 1902. It should be noticed that during the two most doubtful months—March and April—much high water exists, and hence the percentage error during those months is not large. But if the date for changing rating tables was not chosen correctly there is liability of errors from 15 to 40 per cent during the remainder of the doubtful period.

A summary of the records furnishes the following discharge data: Maximum discharge for twenty-four hours, 218,700 second-feet; minimum discharge for twenty-four hours, 900 second-feet; mean annual discharge, 1897 to 1906, inclusive, 10,575 second-feet; mean annual rainfall for eleven years, 36.21 inches.

Discharge measurements of Potomac River at Point of Rocks, Md.

Date.	Gage height.[a]	Discharge.	Date.	Gage height.[a]	Discharge.
1895.	*Feet.*	*Second-feet.*	1900.	*Feet.*	*Second-feet.*
March 25	3.05	10,520	June 28	1.50	3,22
April 5	3.42	14,030	October 2[d]	.30	1,29
April 13	4.27	17,520	September 19	[b].30	1,27
April 23	2.10	7,371			
May 1	4.35	21,070	1901.		
May 7	3.10	12,490	April 16	14.30	108,00
May 17	2.35	8,918	July 29	1.85	6,59
May 28	2.45	9,189	December 27	2.89	11,49
June 3	1.53	4,536			
June 17	1.30	4,233	1902.		
July 10	1.50	4,695	June 22	1.25	2,98
November 6	.40	1,202	September 2	.87	1,77
1896.			1903.		
June 23	1.82	6,462	March 12	4.84	18,80
August 4	1.86	7,057	April 17	13.70	85,60
November 16	1.60	6,109	Do	13.10	80,20
			April 18	9.60	54,60
1897.			September 14	1.50	3,75
February 9	[b]7.95	40,650	November 9	1.12	2,10
February 23[c]	[b]21.70	154,800			
March 8	5.70	27,380	1904.		
March 27	4.05	17,120	July 11	3.87	13,70
July 23	[b]2.85	8,130			
October 29	[b].20	2,141	1905.		
April 12	[b]5.00	20,020	March 13	6.56	28,60
			June 20	1.29	2,95
1898.			October 30	2.05	4,89
January 25	6.50	33,340	November 9	1.20	2,53
August 19	3.30	14,310	Do	1.20	2,95
October 3	.65	1,939			
			1906.		
1899.			May 30	1.70	3,96
January 28	3.80	17,330	Dec. 7	1.76	4,43
May 20	8.15	45,990			
September 5	.80	2,360			
October 29	.50	1,628			

[a] All gage heights refer to datum 41.30 feet below bench mark No. 1, 1895 to 1901, inclusive, and 41.75 feet below the same bench mark, 1902 to 1906.
[b] Gage height inaccurate.
[c] Measurement recomputed, 1905.
[d] Measurement made by wading.

Discharge measurements of Chesapeake and Ohio Canal at Point of Rocks, Md.

Date.	Gage height.	Discharge.
1905.	*Feet.*	*Second-feet.*
October 30	[a] 21.51	75.8
November 9	[a] 21.51	90.0

[a] Elevation of water surface of canal above Potomac River gage datum determined with a level.

Daily gage height, in feet, of Potomac River at Point of Rocks, Md.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	.....	6.1	3.1	3.3	1.8	2.0	1.0	0.6	0.3	0.4	0.4
.....	.....	9.7	3.0	5.9	1.7	2.7	.9	.7	.3	.4	.5
.....	.....	10.6	2.9	5.8	1.5	2.3	.8	.9	.3	.3	.5
.....	.....	9.6	3.6	5.4	1.4	2.1	.8	.7	.3	.3	.5
.....	.....	7.1	3.5	4.4	1.4	1.9	.9	.6	.3	.3	.5
.....	.....	5.6	3.0	3.7	1.4	1.7	.8	.6	.3	.4	.6
.....	.....	4.8	2.7	3.1	1.2	1.5	.8	.6	.3	.3	.8
.....	.....	4.3	2.6	2.7	.8	1.5	.8	.5	.3	.3	.8
.....	.....	4.1	3.0	2.7	1.3	1.7	1.1	.5	.3	.4	.6
.....	.....	4.1	10.8	2.8	1.2	1.6	1.0	.6	.3	.4	.5
.....	.....	4.0	7.9	2.8	1.1	1.5	.9	.5	.3	.4	.5
.....	.....	3.6	5.8	2.7	1.1	1.5	.8	.5	.4	.5	.5
.....	.....	3.6	4.5	2.7	1.2	1.3	.8	.5	.2	.4	.6
.....	.....	3.6	3.8	2.8	1.2	1.2	.7	.5	.2	.4	1.6
.....	.....	4.7	3.5	3.0	1.5	1.1	.7	.5	.3	.4	.6
.....	.....	5.9	3.4	2.6	1.3	1.0	.6	.5	.3	.4	.5
.....	1.6	8.1	3.3	2.4	1.2	1.0	.6	.4	.3	.4	.4
.....	1.6	6.9	3.0	2.3	1.1	1.0	.6	.4	.3	.4	.4
.....	1.6	5.4	2.7	2.2	1.1	1.1	.6	.5	.3	.4	.3
.....	1.6	4.9	2.6	2.4	1.0	1.0	.6	.5	.3	.4	.3
.....	1.7	4.1	2.4	2.3	.9	1.0	.6	.4	.2	.4	.3
.....	1.8	3.8	2.2	2.4	1.0	1.0	.5	.4	.2	.4	.6
.....	2.0	3.4	2.1	2.8	1.0	1.1	.5	.4	.2	.4	.6
.....	2.0	3.2	2.0	3.8	.9	.9	.5	.5	.3	.4	1.3
.....	2.0	3.0	2.0	3.3	.8	.9	.4	.5	.3	.4	1.3
.....	2.1	2.9	1.9	2.6	.8	1.0	.4	.4	.3	.4	1.2
.....	2.9	3.0	1.8	2.5	1.2	1.2	.4	.4	.3	.4	1.3
.....	3.6	3.8	1.8	2.4	2.1	1.3	.4	.4	.3	.5	1.4
.....	.....	3.2	1.8	2.4	1.6	1.2	.4	.3	.3	.5	.9
.....	.....	4.3	2.2	2.2	1.5	1.1	.5	.3	.3	.4	.9
.....	.....	3.5	.....	2.0	.....	1.1	.5	.....	.3	.....	1.3
1.3	1.3	.....	.....	.....	1.1	1.6	2.0	.5	21.85	.8	2.0
1.2	1.2	.....	.....	.....	.8	1.4	2.2	.5	12.05	.8	3.0
1.3	1.3	.....	.....	.....	.6	1.2	2.5	.4	6.3	.7	2.8
1.4	1.8	.....	.....	.....	.5	1.1	2.0	.4	4.0	.7	2.3
1.4	2.8	.....	.....	.....	.4	1.0	1.8	.4	3.0	.8	2.0
1.4	3.5	.....	.....	.....	.3	1.3	1.6	.5	2.4	6.0	1.8
1.3	7.0	.....	.....	.....	.6	1.2	1.4	.3	2.1	6.0	1.7
1.3	7.0	.....	.....	.....	.6	1.6	1.2	.3	1.8	5.1	1.7
1.3	5.0	.....	.....	.....	1.6	1.9	1.1	.3	1.5	3.8	1.6
1.3	3.8	.....	.....	.....	2.0	2.5	1.2	.3	1.3	3.0	1.5
1.0	2.9	.....	.....	0.8	2.2	4.0	1.1	.4	1.2	2.5	1.7
.8	2.8	.....	.....	.7	1.7	3.8	1.0	.3	1.1	2.2	1.7
.7	2.4	.....	.....	.6	1.4	2.7	1.0	.3	1.1	1.9	1.6
.6	2.3	.....	.....	.6	1.1	2.3	1.1	.3	1.0	1.7	1.5
.5	2.7	.....	.....	.5	1.0	2.3	1.1	.3	1.0	1.5	1.4
.5	3.9	.....	.....	1.6	1.1	1.6	1.1	.8	1.0	1.5	1.3
.5	3.5	.....	.....	1.1	1.2	1.5	1.2	.5	1.0	1.4	1.2
.4	2.9	.....	.....	1.0	3.4	1.4	1.0	.4	1.0	1.3	1.1
.3	2.3	.....	.....	.8	3.2	1.4	.8	.4	.9	1.2	1.0
.3	1.3	.....	.....	.6	2.7	1.3	.7	.7	.9	1.1	1.0
.3	.9	.....	.....	.6	2.2	1.2	.6	.4	.8	1.0	1.0
.5	1.1	.....	.....	.7	1.8	1.1	.6	.5	.8	1.0	1.0
.6	1.5	.....	.....	1.0	1.8	1.2	.6	.4	.8	1.0	1.0
2.3	1.5	.....	.....	1.0	1.8	1.6	.6	.4	.7	1.0	1.0
5.1	1.6	.....	.....	.9	1.6	3.3	.6	.3	.7	.9	.9
4.8	1.4	.....	.....	.8	1.7	8.7	.5	.4	.9	.9	1.1
3.7	1.3	.....	.....	.7	1.9	6.0	.5	.4	1.0	.9	1.0
2.9	1.2	.....	.....	.6	2.3	3.3	.5	.3	.9	1.0	.7
2.1	1.8	.....	.....	.8	2.0	2.7	.6	.4	.9	1.0	.7
1.6	.....	.....	.....	1.0	1.8	2.8	.6	5.3	.8	1.2	.8
1.4	.....	.....	.....	1.6	.....	2.4	.5	.....	.8	.....	.9

Gage heights January 1 to June 17, 1896, approximate. See Introduction, page 31.

See description of station in regard to datum of gage.

Daily gage height, in feet, of Potomac River at Point of Rocks, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897.[a]												
1	0.8	2.0	5.3	2.3	1.7	2.0	1.3	1.5	1.0	0.7	0.7	0
2	.8	1.9	4.4	2.2	1.9	1.9	1.2	1.4	.9	.7	.8	1
3	.8	2.5	4.2	2.1	6.5	1.8	1.3	1.3	.9	.7	1.0	1
4	.9	2.0	4.1	2.1	14.0	1.9	1.3	1.3	.9	.7	1.4	1
5	.9	2.1	4.6	2.2	8.5	2.0	1.2	1.3	.9	.7	1.0	1
6	1.0	5.1	5.4	2.5	6.0	2.0	1.2	1.8	.9	.6	.8	1
7	1.4	8.0	6.0	2.8	5.4	1.9	1.2	1.3	.9	.6	.7	1
8	1.7	10.5	5.8	3.0	4.6	2.0	1.2	1.2	.8	.6	.5	1
9	1.5	7.9	5.0	2.9	4.0	2.0	1.1	1.3	.8	.6	.5	1
10	1.3	5.8	4.5	3.7	3.5	1.8	1.0	1.3	.8	.6	.5	1
11	1.1	4.6	4.2	5.7	3.2	1.7	1.4	1.4	.7	.7	.7	1
12	1.1	4.0	4.0	4.6	3.0	1.7	1.3	1.3	.7	.8	1.2	1
13	1.1	3.9	3.9	3.9	3.3	1.6	1.3	1.3	.7	.6	.8	1
14	.9	4.6	3.7	3.5	8.9	1.6	1.4	1.2	.8	.7	.5	1
15	.9	5.7	3.7	3.3	12.6	1.7	1.4	1.2	.8	.7	.5	1
16	1.0	7.0	3.8	3.1	8.0	1.7	1.5	1.3	.7	.6	.6	1
17	.9	7.4	4.2	3.0	5.0	1.6	1.3	1.2	.7	.6	1.1	1
18	.9	7.7	4.4	2.9	4.4	1.6	1.1	1.2	.7	.6	.9	1
19	.9	7.6	4.7	2.8	4.1	1.7	1.4	1.1	.7	.6	.7	1
20	1.5	7.2	5.3	2.6	3.9	1.7	1.4	1.1	.7	.6	.7	1
21	1.5	6.4	6.2	2.5	3.5	2.1	2.1	1.1	.7	.6	.6	1
22	1.4	6.7	6.0	2.3	3.2	2.0	2.6	1.1	.7	.7	.6	1
23	1.4	21.2	5.5	2.2	2.9	1.8	2.7	1.1	.8	.6	.6	1
24	1.4	24.6	4.8	2.1	2.8	1.7	2.1	1.2	1.0	.6	.4	1
25	1.5	16.8	4.7	2.1	2.9	1.6	1.9	1.7	.8	.7	.4	1
26	1.8	9.3	4.6	2.0	3.0	1.6	1.9	1.6	.8	.7	.4	1
27	2.0	7.3	4.1	1.9	2.8	1.6	2.1	1.3	.9	.7	.8	1
28	2.3	6.0	3.8	1.9	2.5	1.5	2.2	1.3	.9	.8	.6	1
29	2.2	.....	3.6	1.8	2.2	1.4	2.1	1.3	.9	.9	.5	1
30	2.1	.....	3.3	1.7	2.1	1.3	1.9	1.3	.9	.9	.6	1
31	2.0	.....	2.9	.....	2.0	.....	1.8	1.3	.....	.9	.....	1
1898.												
1	1.1	2.8	1.9	6.1	2.6	2.2	.9	1.5	1.2	.7	2.7	2
2	1.1	1.7	1.8	5.2	2.4	2.0	.8	1.7	1.1	.7	2.5	2
3	1.2	2.0	1.7	4.6	2.2	1.8	.8	1.4	1.1	.6	2.3	2
4	1.4	1.9	1.7	4.1	2.0	1.7	.7	1.2	1.0	.7	2.2	5
5	1.4	1.9	1.6	3.8	1.9	1.6	.7	2.2	1.0	.8	2.0	
6	1.5	2.0	1.6	3.6	1.8	1.4	.7	7.2	1.0	.8	1.8	9
7	1.4	2.0	1.6	3.2	2.2	1.3	.7	6.1	1.1	1.0	1.8	6
8	1.1	1.9	1.5	2.9	5.4	1.3	.8	3.7	1.0	1.1	1.7	4
9	1.2	1.9	1.5	2.4	11.05	1.2	.7	3.9	1.0	1.0	1.6	3
10	1.4	1.8	1.4	2.5	9.6	1.2	.7	5.6	.9	1.0	1.6	3
11	2.1	1.8	1.4	2.5	6.5	1.1	.7	14.0	.9	.9	2.0	2
12	4.0	1.9	1.5	2.4	5.2	1.1	.6	16.05	.9	.9	1.8	2
13	3.9	2.0	1.5	2.4	4.2	1.1	.5	9.5	.8	1.4	1.8	2
14	3.5	1.9	1.6	2.5	3.7	1.3	.5	8.0	.8	1.2	2.0	2
15	3.7	1.9	1.6	2.5	3.1	1.3	.5	7.2	.8	1.0	2.0	
16	4.9	2.0	1.7	4.0	3.0	1.3	.5	6.1	.8	.8	1.8	1
17	6.2	2.0	1.7	9.0	3.2	1.3	.5	5.2	.8	.8	1.8	1
18	4.9	1.8	2.0	6.7	4.6	1.2	.5	4.3	.8	.8	1.8	2
19	3.8	1.7	5.8	5.1	4.4	1.5	.7	3.3	.8	1.4	2.2	2
20	3.1	1.7	4.6	4.2	3.5	1.4	.7	3.1	.7	9.0	3.0	
21	2.9	2.8	3.5	3.5	2.3	1.3	.9	3.0	.7	5.4	3.6	2
22	2.8	3.8	3.5	3.2	2.9	1.3	.9	3.8	.7	5.35	3.3	2
23	3.2	4.1	6.6	2.9	3.1	1.3	1.1	2.8	.7	13.1	3.2	2
24	7.6	3.4	6.2	2.6	3.9	1.2	.9	2.3	.7	10.1	3.1	4
25	6.5	2.9	6.4	2.6	5.1	1.1	.8	2.0	.7	5.9	3.0	4
26	5.1	2.6	10.5	2.6	5.6	1.1	.9	1.8	.7	4.5	2.7	3
27	5.0	2.3	7.2	2.5	4.1	1.0	1.2	1.5	.9	3.8	2.6	4
28	5.1	2.1	5.3	3.3	3.4	1.0	1.0	1.5	.8	3.6	2.4	3
29	5.1	.....	4.4	3.0	3.0	.9	1.2	1.4	.7	3.4	2.2	3
30	3.6	.....	4.3	2.8	2.8	.9	1.4	1.3	.7	3.0	2.1	3
31	3.4	.....	6.2	.....	2.4	.....	1.7	1.3	.....	2.8	.....	2

[a] 1897 gage heights subject to errors of several tenths.

gage height, in feet, of Potomac River at Point of Rocks, Md.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
...	3.0	2.4	11.9	5.3	1.6	2.0	1.0	0.7	0.9	0.7	0.8	0.8
...	3.4	2.0	9.2	4.5	1.6	2.4	1.0	.7	.9	.6	1.5	.8
...	2.9	2.1	8.2	4.0	2.1	3.8	1.1	.7	.8	.6	2.5	.8
...	2.7	2.1	7.6	3.6	1.7	2.6	1.0	.9	.8	.6	2.0	.8
...	2.3	2.0	8.5	3.3	1.7	2.1	.9	1.0	.8	.6	1.8	.8
...	4.1	2.0	16.55	3.0	2.1	1.8	1.0	1.1	.7	.6	1.4	.7
...	6.9	2.0	12.9	2.8	2.0	1.6	2.0	1.1	.7	.6	1.4	.7
...	8.1	2.3	10.0	3.0	1.9	1.5	1.0	1.1	.6	.7	1.3	.7
...	6.8	2.3	8.1	3.5	2.0	1.4	1.0	1.0	.6	.7	1.2	.7
...	5.4	3.6	6.0	3.4	2.4	1.7	.9	1.0	.6	.6	1.0	.7
...	4.6	4.2	5.8	4.2	4.5	1.8	.9	.9	.6	.6	.9	.7
...	3.9	4.2	5.6	4.5	3.8	1.7	.8	.8	.8	.6	.9	.8
...	3.6	4.0	5.0	3.4	3.4	1.7	.8	.6	1.2	.6	.8	.8
...	3.4	3.9	4.8	3.2	3.2	1.6	.8	.6	1.1	.5	.8	1.2
...	3.4	3.8	4.5	3.0	2.8	1.5	.9	.6	1.0	.5	.8	3.0
...	4.0	4.0	4.6	2.8	2.5	1.5	1.1	.7	.9	.5	.8	2.1
...	5.7	4.5	4.7	2.7	2.3	1.4	.9	.7	.8	.5	.8	1.7
...	5.2	5.0	4.4	2.6	2.4	1.4	.7	.6	.7	.5	.7	1.5
...	4.7	5.2	5.2	2.5	8.55	1.3	.7	.6	.7	.5	.7	1.6
...	4.4	5.4	5.4	2.4	6.3	1.3	.7	.6	.9	.5	.7	1.5
...	4.0	6.0	5.3	2.2	5.0	1.2	.7	.6	.7	.5	.7	1.3
...	3.5	8.5	4.7	2.1	3.6	1.2	.7	.5	.8	.5	.7	1.1
...	3.3	14.8	4.2	2.0	3.0	1.1	.7	.5	.9	.5	.8	1.0
...	3.2	13.7	4.0	2.0	2.7	1.1	.6	.5	.9	.5	.8	1.2
...	3.3	9.0	3.9	2.0	2.4	1.0	.6	.5	.9	.5	.9	1.8
...	4.8	6.0	3.7	1.9	2.1	1.0	.6	.5	1.0	.5	.9	2.1
...	4.7	9.25	3.5	1.9	2.0	1.0	.6	1.2	.8	.5	.8	1.6
...	3.9	13.9	3.4	1.8	1.8	1.2	.6	1.1	.7	.5	.8	1.5
...	3.2	.....	4.6	1.7	1.7	1.1	.5	1.1	.7	.5	.8	1.6
...	2.8	.....	8.6	1.7	1.7	1.0	.8	1.0	.8	.5	.8	1.6
...	2.6	.....	7.0	.....	1.8	.....	.8	1.0	.....	.6	.....	1.6
...	1.5	1.0	3.5	4.8	1.9	1.3	1.2	1.2	.7	.3	.5	2.4
...	1.5	1.6	4.5	3.8	1.7	1.3	1.1	1.1	.7	.3	.5	1.9
...	1.4	2.0	6.6	3.4	1.6	1.3	1.0	1.0	.6	.3	.5	1.6
...	1.5	2.1	5.9	3.1	1.5	1.4	1.0	.9	.6	.3	.5	1.6
...	1.5	2.2	4.4	2.8	1.5	1.6	.9	.9	.5	.3	.5	2.0
...	1.4	1.9	4.0	2.7	1.4	1.6	1.3	.8	.6	.3	.4	4.1
...	1.4	1.8	3.6	2.6	1.4	1.5	1.0	.8	.5	.3	.4	5.9
...	1.3	1.5	3.9	2.5	1.3	1.4	.9	.7	.4	.3	.4	3.7
...	1.3	1.8	4.5	2.4	1.3	1.4	.8	.6	.4	.3	.5	3.0
...	1.2	2.3	4.0	2.3	1.3	1.3	.7	.6	.3	.3	.6	2.5
...	1.3	3.0	3.6	2.1	1.2	1.2	.6	.5	.4	.3	.5	2.1
...	1.4	2.5	3.2	2.1	1.2	1.1	.6	.5	.3	.3	.4	1.8
...	1.4	3.0	2.9	2.0	1.1	1.0	.5	.4	.3	.3	.4	1.6
...	1.5	4.5	2.8	1.9	1.1	.9	.5	.4	.4	.3	.4	1.5
...	1.8	5.3	2.7	1.9	1.1	1.3	.5	.4	.4	.9	.4	1.4
...	2.1	4.5	2.6	1.8	1.1	1.0	.4	.4	.4	.5	.4	1.4
...	1.9	3.8	2.4	1.8	1.0	1.8	.4	.4	.3	.4	.4	1.5
...	1.7	3.1	2.3	1.7	1.0	2.8	.4	.4	.3	.3	.3	1.2
...	1.6	2.6	2.4	1.7	1.2	8.5	.5	.4	.3	.3	.2	1.1
...	2.2	2.3	2.6	1.6	1.3	6.2	1.4	.4	.3	.3	.2	1.1
...	3.6	1.9	5.8	1.7	1.8	4.6	1.0	.4	.3	.3	.3	1.0
...	6.8	3.0	8.7	2.2	1.9	3.6	.9	.4	.3	.5	.4	.9
...	5.5	6.9	6.6	2.5	2.0	2.7	.8	.4	.3	.4	.4	.9
...	4.0	7.1	5.4	2.8	1.7	2.3	1.8	.4	.3	.4	.4	.8
...	3.3	5.6	5.0	3.0	1.5	2.1	1.6	.5	.3	.4	.4	.8
...	2.8	3.9	4.5	2.8	1.4	2.0	2.0	.6	.3	.4	1.2	.8
...	2.5	3.3	4.1	2.5	1.4	1.8	1.4	.7	.3	.5	3.3	.8
...	2.1	3.0	3.7	2.3	1.3	1.5	1.2	.9	.2	.5	8.2	.8
...	1.8	.....	3.5	2.1	1.2	1.4	1.0	.9	.3	.5	5.4	.8
...	1.3	.....	3.3	2.0	1.3	1.3	1.3	.8	.3	.5	3.2	.8
...	1.2	.....	3.2	.....	1.3	.....	1.3	.8	.....	.5	.....	.8

Daily gage height, in feet, of Potomac River at Point of Rocks, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	De.
1901.[a]												
1	0.8	1.2	.8	2.2	3.4	7.5	2.6	1.7	2.8	3.0	0.9	1
2	.9	1.1	.8	2.0	3.1	6.0	2.4	1.5	5.7	2.4	.9	1
3	.9	1.0	.8	3.3	2.8	4.8	2.3	1.4	5.3	2.1	1.0	1
4	.9	1.1	.8	5.4	2.6	4.0	2.1	1.4	4.1	1.9	1.0	1
5	.9	1.1	.8	7.7	2.5	3.5	2.0	1.3	3.2	1.9	.9	1
6	.8	1.1	.9	6.8	2.3	4.0	2.0	1.3	2.3	1.7	.9	2
7	.7	1.3	1.8	6.8	2.1	4.7	1.9	1.6	2.0	1.5	.9	2
8	.7	1.2	1.4	7.8	1.9	4.8	2.2	4.5	1.8	1.4	.9	2
9	.6	1.2	1.3	6.3	1.8	4.1	2.0	3.5	1.7	1.4	.9	2
10	.6	1.2	2.7	5.3	2.0	3.2	1.7	2.8	1.7	1.3	.9	2
11	.7	1.3	4.2	4.2	8.0	2.7	1.6	2.3	1.6	1.3	.9	2
12	1.1	1.4	12.8	3.3	9.1	2.5	1.5	2.3	1.6	1.2	.9	1
13	1.8	1.7	9.9	3.0	6.0	2.2	1.6	2.2	1.5	1.2	.9	1
14	4.6	1.7	6.2	3.2	4.6	2.4	2.0	2.2	1.5	1.2	.8	1
15	3.5	1.8	4.5	9.0	3.5	2.7	3.6	2.1	1.5	1.2	.5	1
16	2.8	1.7	3.9	15.0	3.0	3.0	5.1	2.0	1.8	1.2	.9	1
17	2.2	1.4	3.2	8.3	2.7	5.7	5.2	2.0	1.6	1.1	.9	1
18	2.0	1.1	2.8	7.4	2.4	8.5	5.5	2.3	1.5	1.1	.9	1
19	1.9	1.1	2.5	6.2	2.3	5.6	5.1	2.4	1.5	1.1	.9	1
20	1.7	1.0	2.3	5.4	2.2	4.5	4.6	2.6	1.4	1.1	.9	1
21	1.5	.9	2.5	11.4	2.0	3.7	3.6	3.0	1.4	1.1	.9	1
22	1.4	.9	3.0	20.8	1.9	5.6	3.1	2.7	1.4	1.1	.9	1
23	1.3	.8	3.2	15.8	12.6	4.6	2.8	2.3	1.3	1.1	.9	1
24	1.3	.9	3.3	11.2	14.2	4.5	2.5	2.0	1.3	1.0	1.8	1
25	1.4	.9	2.8	7.9	9.3	4.3	2.2	2.0	1.3	1.0	4.1	1
26	1.5	.9	2.5	6.6	7.2	4.0	2.1	2.0	1.2	1.0	4.4	2
27	1.5	1.0	2.6	5.6	7.5	3.6	2.2	2.2	1.2	1.0	3.2	1
28	1.3	1.0	2.5	4.8	7.6	3.3	2.0	2.7	1.2	.9	2.5	1
29	.9	.....	2.6	4.2	9.0	3.0	1.8	2.4	1.2	.9	2.0	4
30	1.0	.....	2.7	3.8	9.7	2.8	1.7	2.2	3.2	.9	1.7	1
31	1.2	.....	2.4	.....	8.6	.....	1.7	2.3	.....	.9	.....	1
1902.[b]												
1	11.7	3.7	22.5	5.7	2.7	1.8	1.6	1.6	.8	1.2	1.0	2
2	7.2	3.5	20.0	5.0	2.6	1.8	1.7	1.4	.9	1.2	1.0	2
3	5.6	3.3	16.1	4.5	2.6	1.7	1.8	1.7	.9	1.1	1.0	2
4	4.8	3.2	10.2	4.1	2.6	1.6	1.8	1.7	.9	1.0	1.0	3
5	4.2	2.8	8.1	4.0	2.5	1.6	1.7	1.8	.9	1.1	1.0	5
6	3.8	2.4	6.7	3.8	2.5	1.5	1.7	1.6	.9	1.2	1.0	4
7	3.5	2.5	5.8	4.0	2.5	1.5	1.6	1.5	.8	1.2	.9	4
8	3.2	2.6	6.7	6.4	2.4	1.5	1.6	1.5	.8	1.1	.9	4
9	3.1	2.5	7.4	16.4	3.1	1.4	1.5	1.4	.8	1.1	.9	3
10	3.0	2.5	8.5	14.3	2.7	1.4	1.5	1.3	.8	1.1	.9	3
11	2.8	3.5	12.0	12.9	2.5	1.4	1.5	1.2	.8	1.1	.9	3
12	2.7	4.0	12.4	12.2	2.3	1.4	1.4	1.1	.8	1.4	.9	3
13	2.5	4.2	14.0	11.5	2.2	1.3	1.4	1.1	.7	1.6	1.0	4
14	2.3	4.4	13.8	9.3	2.2	1.4	1.4	1.0	.7	1.9	1.0	6
15	2.1	5.2	12.0	7.8	2.1	1.4	1.3	1.0	.7	2.0	1.0	7
16	2.1	5.4	10.2	6.5	2.1	1.4	1.3	1.0	.7	2.1	1.0	8
17	2.1	5.5	8.2	5.9	2.0	1.3	1.2	1.0	.7	2.0	1.0	8
18	2.1	5.2	10.6	5.3	1.9	1.3	1.2	1.0	.7	1.8	1.0	9
19	2.1	4.8	8.7	4.9	1.9	1.3	1.2	1.0	.7	1.6	1.0	8
20	2.1	4.5	6.6	4.6	2.6	1.3	1.2	1.0	.7	1.4	1.0	5
21	2.3	4.5	5.5	4.0	2.0	1.3	1.3	.9	.7	1.2	.9	5
22	3.0	5.6	4.5	3.5	2.0	1.3	1.3	.9	.7	1.1	.9	4
23	6.7	7.0	4.1	3.3	1.9	1.3	1.2	.9	.7	1.0	.9	5
24	5.2	4.1	3.8	3.0	1.9	1.3	1.1	.9	.7	.9	.9	5
25	3.2	4.4	3.6	2.9	1.9	1.2	1.1	1.0	.9	.9	1.3	4
26	3.0	17.75	3.5	2.8	2.0	1.4	1.1	1.0	.8	.9	1.5	4
27	3.5	27.2	3.5	2.9	2.2	1.5	1.0	.9	.8	.8	1.9	3
28	5.2	18.0	3.6	2.8	2.0	1.4	1.0	.9	.8	1.0	3.0	3
29	5.0	.....	3.7	2.7	1.9	1.4	1.0	1.0	.8	1.0	3.5	3
30	4.5	.....	4.3	2.7	1.9	1.4	1.6	.9	1.0	1.1	2.8	2
31	4.2	.....	6.4	.....	1.9	.....	1.7	.8	.....	1.1	.....	2

[a] Gage heights April 16 to December 31, 1901, are somewhat in error on account of uncertainty of the gage datum.

[b] Gage heights January 1 to September 1, 1902, somewhat in error; datum not known. Gage heights September 2 to December 31, 1902, refer to datum 41.75 feet below bench mark No. 1. Rise in gage February 11-23, 1902, due to ice gorging.

Daily gage height, in feet, of Potomac River at Point of Rocks, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.[a]												
	2.6	6.5	14.2	7.7	3.0	3.7	8.7	1.7	2.0	1.2	1.1	1.1
	2.4	6.1	15.3	7.0	2.9	4.9	5.8	1.7	2.1	1.1	1.1	1.1
	4.9	6.0	8.9	6.1	2.8	4.0	4.5	1.6	2.2	1.1	1.0	1.1
	11.6	6.3	6.6	5.0	2.8	3.4	4.0	1.7	2.1	1.1	1.0	1.1
	10.3	8.2	5.7	4.9	2.8	3.0	3.5	1.8	2.0	1.0	1.0	1.1
	7.6	9.2	5.3	4.6	2.7	2.6	4.7	1.9	1.9	1.0	1.0	1.1
	5.7	6.7	5.0	4.3	2.7	2.4	8.2	2.3	1.8	1.0	1.0	1.1
	4.8	6.3	4.8	4.1	2.6	6.4	5.8	2.3	1.7	1.1	1.1	1.1
	4.2	5.2	4.6	4.5	2.5	8.2	4.0	2.2	1.6	2.3	1.1	1.0
	3.5	4.5	4.8	6.1	2.4	7.4	3.4	2.0	1.5	2.0	1.1	1.0
	3.0	4.1	5.4	5.6	2.3	6.5	3.0	2.9	1.5	1.9	1.0	1.0
	2.8	3.7	5.0	5.4	2.3	5.1	3.5	2.8	1.4	1.8	1.0	1.0
	2.7	3.7	4.6	5.3	2.2	5.3	5.6	2.5	1.4	1.8	1.0	1.0
	2.6	3.9	4.3	5.6	2.1	6.0	3.9	2.3	1.5	1.7	1.0	1.0
	2.7	3.9	4.0	14.4	2.1	5.6	3.5	2.0	1.5	1.7	1.0	1.1
	2.8	4.0	3.8	15.1	2.0	4.5	3.2	2.0	1.4	1.6	1.0	1.2
	2.9	6.8	3.6	14.0	2.0	4.0	3.0	1.9	1.5	1.5	1.1	1.7
	2.8	7.4	3.4	10.4	1.9	3.6	2.8	1.8	2.6	1.5	1.1	1.5
	2.8	6.0	3.2	7.8	1.9	3.2	2.8	1.8	4.5	1.5	1.1	1.4
	2.8	4.9	3.1	6.7	1.9	3.0	3.1	1.7	2.9	1.6	1.1	1.5
	2.9	4.5	3.0	5.5	1.8	2.8	2.8	1.7	2.4	1.6	1.1	1.6
	3.6	4.2	3.1	5.0	1.8	2.6	2.5	1.6	2.0	1.5	1.1	1.7
	4.4	4.1	5.1	4.5	1.8	2.4	2.3	1.6	1.9	1.5	1.1	1.7
	3.8	3.8	7.0	4.1	1.9	2.5	2.1	1.5	1.7	1.4	1.2	1.6
	3.3	4.2	12.1	3.8	2.0	3.3	2.0	1.4	1.6	1.4	1.1	1.6
	3.1	4.4	8.6	3.6	2.0	3.6	2.0	1.3	1.4	1.3	1.0	1.6
	2.8	4.5	6.6	3.5	2.1	3.2	1.9	1.3	1.3	1.3	1.0	1.6
	3.6	5.4	5.3	3.4	2.3	2.7	1.9	1.5	1.3	1.2	1.3	1.6
	6.2	.....	4.7	3.2	2.4	6.2	1.8	2.1	1.2	1.2	1.1	1.7
	7.3	.....	4.5	3.1	2.6	12.2	2.0	2.5	1.2	1.1	1.1	1.7
	7.0	.....	5.1	.....	2.8	.....	1.8	2.1	.....	1.1	.....	1.6
1904.[b]												
	1.5	3.0	5.3	2.4	5.6	6.7	1.4	1.4	.9	.6	.6	.8
	1.5	2.9	4.4	2.6	4.0	7.8	1.3	1.3	.8	.6	.6	.8
	2.0	2.9	4.0	3.0	3.6	5.2	1.3	1.2	.8	.6	.7	.8
	2.3	3.3	3.8	3.5	3.0	4.6	1.3	1.2	.8	.6	.7	.8
	1.8	4.8	4.0	3.1	2.8	4.1	1.2	1.2	.9	.6	.7	.8
	1.5	4.9	4.2	3.5	2.6	5.0	1.5	1.2	1.0	.6	.7	.8
	1.5	4.9	4.5	3.0	2.5	4.4	1.5	1.3	.9	.6	.7	.8
	1.5	3.3	5.0	2.4	2.8	4.0	1.6	1.4	.8	.6	.7	.8
	1.6	3.5	4.8	2.3	2.7	3.6	1.6	1.5	.7	.5	.7	.8
	1.6	5.7	5.4	2.3	2.6	3.2	1.7	1.4	.7	.5	.7	.9
	1.6	5.0	4.5	2.6	2.5	2.8	2.9	1.3	.7	.5	.7	.9
	1.7	3.9	3.8	3.1	2.5	2.6	2.6	1.3	.8	.6	.7	.9
	1.6	3.6	3.3	2.8	2.4	2.5	3.4	1.2	1.0	.7	.7	.9
	1.6	3.5	2.8	2.6	2.3	2.4	3.1	1.2	.9	.7	.8	.9
	1.6	3.4	2.6	2.5	2.2	2.2	3.0	1.1	.9	.6	.8	.9
	1.5	3.8	2.4	2.2	2.2	2.1	2.8	1.1	1.0	.6	.8	.9
	1.5	3.8	2.4	2.1	2.1	2.0	2.4	1.1	1.0	.5	.7	.9
	1.5	3.9	2.2	2.1	2.2	1.8	2.0	1.0	.9	.5	.8	.9
	1.5	3.9	2.1	2.0	2.3	1.6	1.8	1.0	.8	.5	.8	.9
	1.5	3.8	2.2	1.9	3.1	1.5	1.6	1.0	.7	.6	.8	1.0
	1.5	3.8	2.3	1.9	6.2	1.5	1.4	1.0	.8	1.0	.7	1.0
	2.0	4.5	2.4	1.8	4.7	2.5	1.4	.9	1.0	.9	.7	1.0
	4.0	5.6	2.5	1.7	4.0	3.0	1.3	.9	.9	.8	.7	1.0
	5.2	6.0	2.7	1.7	3.6	2.8	1.3	1.0	.8	.7	.7	1.0
	7.4	6.6	3.7	1.6	3.1	2.5	1.3	1.0	.8	.7	.7	1.1
	5.1	6.6	3.4	1.5	2.8	2.1	1.4	1.2	.8	.7	.7	1.4
	3.6	7.6	3.0	1.6	2.5	1.7	1.4	1.1	.7	.7	.7	1.5
	3.3	6.6	2.8	2.0	2.4	1.5	1.4	1.1	.7	.7	.7	1.8
	3.2	6.0	2.6	3.7	2.3	1.5	1.5	1.0	.7	.6	.8	1.8
	3.0	.....	2.5	6.3	2.2	1.4	1.5	1.0	.7	.6	.8	1.9
	3.0	.....	2.4	.....	2.4	.....	1.5	.9	.....	.6	.....	2.0

[a] Ice conditions December 17 to 31, 1903.
[b] Ice conditions during part of January and February, 1904.

Daily gage height, in feet, of Potomac River at Point of Rocks, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	De
1905.												
1	2.0	2.4	2.4	3.2	1.6	1.5	2.1	2.9	2.2	1.0	1.6	1
2	2.4	2.4	2.5	3.0	1.6	1.4	1.8	2.7	2.0	1.0	1.5	1
3	2.5	2.3	2.6	2.7	1.6	1.4	1.6	2.4	1.8	1.0	1.5	2
4	2.8	2.2	2.8	2.5	1.5	1.4	1.5	2.2	1.7	1.0	1.4	4
5	3.0	2.2	3.4	2.6	1.5	1.3	3.0	2.0	1.6	1.0	1.4	4
6	3.2	2.2	4.0	2.7	1.5	1.3	3.5	1.8	1.5	1.0	1.3	3
7	4.4	2.2	4.4	2.8	1.4	1.5	4.0	1.6	1.5	1.0	1.3	3
8	4.6	2.1	5.1	3.0	1.4	1.6	4.5	1.5	1.4	1.0	1.3	2
9	4.0	2.1	6.0	3.0	1.4	1.9	4.0	1.5	1.4	1.0	1.2	2
10	3.4	2.0	6.4	2.9	1.4	2.0	3.6	1.4	1.3	.9	1.2	2
11	3.0	2.0	11.0	2.8	1.4	1.9	2.8	1.4	1.3	.9	1.0	21
12	2.8	2.0	10.1	2.8	1.4	1.9	2.3	1.3	1.4	1.2	1.0	20
13	2.6	2.0	6.9	2.9	1.4	2.3	3.2	1.3	1.4	1.1	1.0	19
14	2.5	2.0	6.0	2.8	1.4	2.2	4.1	1.3	2.0	1.4	1.0	18
15	2.5	2.0	5.9	2.6	3.0	2.0	5.0	1.6	1.7	1.6	1.0	18
16	2.9	2.0	5.5	2.4	2.8	2.0	5.4	2.0	1.5	1.5	1.0	17
17	3.8	2.1	5.0	2.3	2.7	1.9	4.2	2.9	1.4	1.3	1.0	17
18	3.2	2.1	4.5	2.2	2.6	1.8	4.0	3.4	1.4	1.2	.9	17
19	2.8	2.1	4.4	2.1	2.5	1.6	3.6	2.5	1.4	1.0	.9	1
20	2.6	2.2	5.0	2.0	2.4	1.4	3.3	2.1	1.3	1.2	.9	1
21	2.6	2.2	5.9	2.0	2.3	1.3	3.0	1.8	1.3	1.4	.9	
22	2.7	2.2	7.5	1.9	2.2	1.5	2.8	1.7	1.2	1.8	.9	
23	2.8	2.2	8.4	1.9	2.2	2.5	2.6	1.5	1.2	1.6	.9	
24	2.4	2.2	6.7	1.9	2.0	3.6	4.0	1.5	1.2	1.4	.9	
25	2.1	2.2	5.8	1.9	1.8	5.2	3.5	2.0	1.2	1.4	.9	
26	1.9	2.3	6.9	1.8	1.7	7.0	3.0	2.9	1.1	1.5	.9	
27	[a]3.0	2.3	5.9	1.8	1.6	5.0	2.6	3.4	1.1	1.6	.9	
28	2.6	2.4	5.2	1.7	1.5	3.6	2.3	3.9	1.1	1.7	.9	
29	2.6	.....	4.6	1.7	1.5	3.0	2.0	2.9	1.1	2.1	.9	
30	2.5	.....	4.0	1.7	1.4	2.6	1.8	2.8	1.0	2.0	1.3	
31	2.5	.....	3.6	.....	1.3	.....	2.5	2.5	.....	1.8	.....	
1906.[b]												
1	3.6	3.0	1.9	11.1	3.3	1.8	2.2	1.6	3.7	1.2	2.6	
2	3.4	2.9	1.8	9.6	3.1	1.7	1.9	1.5	3.1	1.2	2.5	
3	3.3	2.7	1.8	7.7	2.8	1.7	2.0	1.5	2.8	1.4	2.3	
4	3.7	2.5	2.0	6.5	2.8	1.6	2.9	4.3	2.6	1.5	2.3	
5	8.0	2.4	4.0	5.5	2.6	1.5	2.6	3.6	2.3	2.2	2.1	
6	8.6	2.2	5.45	5.1	2.5	1.7	2.4	2.8	2.1	2.5	2.1	
7	7.0	2.2	4.5	4.8	2.6	1.9	2.2	2.4	1.9	2.7	2.1	
8	4.8	2.0	3.6	4.8	2.5	1.7	2.0	2.6	1.8	2.6	2.0	
9	4.0	1.9	3.0	4.3	2.4	2.4	1.9	2.8	1.8	2.5	2.0	
10	3.5	1.8	2.7	4.2	2.4	3.0	1.7	3.2	1.7	2.2	1.9	
11	3.1	1.8	2.6	5.5	2.4	2.5	1.5	7.6	1.7	2.0	1.8	
12	2.9	1.9	2.5	5.6	2.2	2.2	1.4	5.7	1.6	1.9	1.8	
13	2.8	1.8	2.3	4.9	2.3	1.8	1.3	4.3	1.6	1.6	1.8	
14	3.0	1.8	2.3	4.0	2.2	1.6	1.2	3.7	1.5	1.5	1.7	
15	3.3	1.9	2.3	5.75	2.0	1.6	1.3	3.0	1.5	1.6	1.8	
16	3.6	1.8	2.4	8.45	2.1	1.6	1.2	5.1	1.4	1.4	1.7	
17	3.7	1.7	2.5	7.5	2.0	1.6	1.2	4.8	1.6	1.4	1.8	
18	4.1	1.6	2.5	6.3	1.8	2.5	1.5	4.2	1.5	1.5	1.9	
19	3.9	1.6	2.6	5.1	1.9	3.2	1.8	3.5	1.4	1.7	1.9	
20	3.5	1.6	2.9	4.5	1.8	2.9	1.7	4.4	1.4	12.5	1.9	
21	3.4	1.7	2.9	4.1	1.6	3.1	1.5	4.0	1.4	16.1	3.0	
22	3.3	1.8	3.1	3.6	1.6	5.0	1.4	5.3	1.3	11.65	4.0	
23	3.2	1.9	3.4	3.3	1.6	4.3	1.5	4.8	1.3	8.5	4.0	
24	3.1	2.0	3.9	3.1	1.4	3.6	2.0	3.7	1.3	6.6	3.9	
25	6.35	2.0	3.9	2.9	1.5	3.1	2.1	4.1	1.3	5.4	3.9	
26	5.1	1.9	3.9	2.9	1.4	2.6	1.9	4.8	1.3	4.5	2.7	
27	4.2	1.8	3.7	2.8	1.3	2.4	1.7	4.6	1.2	4.1	2.6	
28	3.6	2.0	7.8	5.1	1.9	2.3	1.8	6.7	1.2	3.6	2.5	
29	3.4	.....	12.9	5.0	1.9	3.1	1.9	6.0	1.2	3.3	2.4	
30	3.2	.....	10.5	4.3	1.7	3.0	2.0	5.3	1.2	3.1	2.4	
31	3.1	.....	10.9	.....	1.7	.....	1.7	4.4	.....	2.8	.....	

[a] Ice gorge January 27, 1905.
[b] Flow probably unaffected by ice conditions during 1906.

Rating tables for Potomac River at Point of Rocks, Md.

FEBRUARY 17, 1895, TO MARCH 31, 1902.[a]

Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Second-feet.	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1,040	2.00	7,120	3.80	16,380	7.20	38,560
1,180	2.10	7,580	3.90	16,940	7.40	40,080
1,340	2.20	8,060	4.00	17,520	7.60	41,600
1,540	2.30	8,540	4.20	18,680	7.80	43,160
1,760	2.40	9,020	4.40	19,840	8.00	44,720
2,000	2.50	9,500	4.60	21,040	8.50	48,700
2,280	2.60	10,000	4.80	22,240	9.00	52,700
2,600	2.70	10,500	5.00	23,480	10.00	61,000
2,940	2.80	11,000	5.20	24,740	11.00	69,300
3,300	2.90	11,520	5.40	26,020	12.00	77,600
3,680	3.00	12,040	5.60	27,340	13.00	85,900
4,080	3.10	12,560	5.80	28,660	14.00	94,200
4,480	3.20	13,080	6.00	30,020	15.00	102,500
4,900	3.30	13,620	6.20	31,380	16.00	110,800
5,320	3.40	14,160	6.40	32,780	17.00	119,100
5,760	3.50	14,700	6.60	34,180	18.00	127,400
6,200	3.60	15,260	6.80	35,620	19.00	135,700
6,660	3.70	15,820	7.00	37,080	20.00	144,000

APRIL 1, 1902, TO DECEMBER 31, 1906.[b]

900	2.30	6,130	4.20	15,150	7.80	38,500
1,090	2.40	6,520	4.40	16,270	8.00	39,980
1,295	2.50	6,920	4.60	17,430	8.50	43,740
1,515	2.60	7,330	4.80	18,610	9.00	47,600
1,750	2.70	7,750	5.00	19,820	9.50	51,560
2,000	2.80	8,180	5.20	21,060	10.00	55,600
2,260	2.90	8,620	5.40	22,300	11.00	63,900
2,530	3.00	9,070	5.60	23,560	12.00	72,200
2,810	3.10	9,530	5.80	24,840	13.00	80,500
3,100	3.20	10,000	6.00	26,140	14.00	88,800
3,400	3.30	10,480	6.20	27,460	15.00	97,100
3,700	3.40	10,970	6.40	28,780	16.00	105,400
4,010	3.50	11,470	6.60	30,100	17.00	113,700
4,330	3.60	11,980	6.80	31,460	18.00	122,000
4,670	3.70	12,490	7.00	32,820	19.00	130,300
5,020	3.80	13,010	7.20	34,220	20.00	138,600
5,380	3.90	13,530	7.40	35,620		
5,750	4.00	14,070	7.60	37,060		

ble is strictly applicable only for open-channel conditions. It is based on 23 discharge nade during 1895–1901, inclusive. It is well defined between gage heights 0.3 foot and 9.00 feet the rating curve is a tangent, the difference being 830 per tenth.

strictly applicable only for open-channel conditions. It is based on discharge measure- ing 1902–1906, inclusive. It is fairly well defined between gage heights 1.0 foot and 14.0 ge height 10.0 feet the rating curve is a tangent, the difference being 830 per tenth.

Estimated monthly discharge of Potomac River at Point of Rocks, Md.

[Drainage area, 9,650 square miles. a]

Month.	Discharge in second-feet.			Run-off.			Precipitation	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Excess
1895.								
January							3.25	
February 17–28	15,200	5,320	7,413	0.768	0.343		b 1.16	
March	65,080	11,520	24,560	2.54	2.93	122	2.41	+0
April	67,640	6,200	14,500	1.50	1.67	71	2.37	
May	29,340	7,120	12,540	1.30	1.50	61	2.46	
June	7,580	2,280	4,033	.418	.466	12	3.88	
July	10,500	2,600	4,443	.460	.530	18	3.03	
August	3,300	1,340	1,997	.207	.239	11	2.10	
September	2,600	1,180	1,565	.162	.181	21	.85	
October	1,340	1,040	1,163	.120	.138	12	1.19	
November	1,540	1,180	1,333	.138	.154	11	1.37	
December	5,320	1,180	2,259	.234	.270	10	2.39	
The year							26.66	
1896.								
January c	24,100	1,180	5,257	.545	.628	32	1.97	
February c	37,080	2,600	10,470	1.08	1.16	33	3.48	
March							3.55	
April							1.61	
May 11–31 c	5,320	1,540	2,500	.265	.207		a 2.91	
June c	14,160	1,180	5,429	.562	.627	13	5.01	
July	50,300	2,940	9,283	.962	1.11	19	5.79	
August	9,500	1,540	3,449	.357	.412	24	1.69	
September	25,380	1,180	2,175	.225	.251	4	6.09	
October	159,400	2,000	12,490	1.29	1.49	162	.92	
November	30,020	2,000	6,928	.718	.801	26	3.02	
December	12,040	2,000	4,723	.489	.564	76	.74	
The year							b 36.78	
1897. d								
January	8,540	2,280	4,284	.444	.512	33	1.55	
February	182,200	6,660	42,660	4.42	4.60	78	5.88	
March	31,380	11,520	20,850	2.16	2.49	104	2.40	
April	28,000	5,760	10,830	1.12	1.25	55	2.28	
May	94,200	5,760	22,950	2.38	2.74	57	4.77	
June	7,580	4,080	5,997	.621	.693	28	2.43	
July	10,500	2,940	5,315	.551	.635	16	4.08	
August	6,200	3,300	4,092	.424	.489	17	2.93	
September	2,940	2,000	2,337	.242	.270	17	1.60	
October	2,600	1,760	1,968	.204	.235	17	1.43	
November	4,480	1,340	2,096	.217	.242	6	4.10	
December	19,260	2,600	6,579	.681	.785	24	3.22	
The year	182,200	1,340	10,830	1.12	14.94	41	36.68	
1898.								
January	41,600	3,300	14,660	1.52	1.75	46	3.78	
February	18,100	5,760	8,339	.864	.900	84	1.07	
March	65,150	4,480	15,470	1.60	1.84	41	4.44	
April	52,700	9,020	15,970	1.65	1.84	78	2.36	
May	69,720	6,200	18,060	1.87	2.16	45	4.76	
June	8,060	2,600	4,178	.433	.483	27	1.81	
July	5,760	1,540	2,418	.250	.288	9	3.21	
August	111,400	3,080	22,140	2.29	2.64	38	7.00	
September	3,680	2,000	2,497	.259	.289	22	1.32	
October	80,730	1,760	13,580	1.41	1.63	25	6.41	
November	15,260	5,320	8,557	.886	.988	41	2.41	
December	54,360	6,200	15,330	1.59	1.83	63	2.91	
The year	111,400	1,540	11,780	1.22	16.64	40	41.48	

a 9,650 square miles used to obtain run-off for 1896; 9,654 used for all other years.

b Precipitation for complete month, February 1895, and May, 1896.

c Estimates January 1 to June 17, 1896, liable to considerable error, owing to possible errors in heights. See Introduction, page 31.

d 1897 estimates may be only approximate, owing to large errors in the wire length during [illegible]. See Introduction, page 32.

ed monthly discharge of Potomac River at Point of Rocks, Md.—Continued.

	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
.....	45,500	8,540	20,870	2.16	2.49	98	2.54	0.05
.....	100,800	7,120	28,130	2.91	3.03	70	4.44	1.41
.....	115,400	14,160	35,240	3.65	4.21	106	3.96	—.25
.....	25,380	5,760	11,750	1.22	1.36	99	1.37	.01
.....	49,140	5,320	11,600	1.20	1.38	27	5.15	3.77
.....	16,380	2,940	5,314	.550	.614	18	3.47	2.86
.....	7,120	1,540	2,519	.261	.301	13	2.28	1.98
.....	3,680	1,540	2,335	.242	.279	10	2.84	2.56
.....	3,680	1,760	2,345	.243	.271	7	3.94	3.67
.....	2,000	1,540	1,663	.172	.198	11	1.88	1.68
.....	9,500	2,000	3,171	.328	.366	22	1.69	1.32
.....	12,040	2,000	4,068	.421	.485	25	1.94	1.46
ear.....	115,400	1,540	10,750	1.11	14.98	42	35.50	20.52
.....	35,620	3,680	8,166	.846	.975	47	2.10	1.12
.....	37,820	2,940	13,340	1.38	1.44	42	3.44	2.00
.....	50,300	8,540	18,470	1.91	2.20	64	3.42	1.22
.....	22,240	5,320	9,295	.963	1.07	80	1.34	.27
.....	7,120	2,940	4,466	.463	.534	23	2.32	1.79
.....	48,700	2,600	8,394	.869	.970	23	4.19	3.22
.....	7,120	1,340	3,008	.312	.360	10	3.74	3.38
.....	3,680	1,340	1,917	.199	.229	11	2.08	1.85
.....	2,000	1,040	1,344	.139	.155	8	1.95	1.79
.....	2,600	1,180	1,333	.138	.159	8	2.08	1.92
.....	46,300	1,040	4,570	.473	.528	15	3.62	3.09
.....	29,340	2,280	6,218	.644	.742	42	1.77	1.03
ear.....	50,300	1,040	6,710	.695	9.36	29	32.04	22.68
.....	21,040	1,760	4,929	.511	.589	30	1.95	1.36
.....	6,200	2,280	3,649	.378	.394	85	.46	.07
.....	80,920	2,280	13,800	1.43	1.65	48	3.46	1.81
.....	150,600	7,120	39,750	4.12	4.60	76	6.05	1.45
.....	95,860	6,200	26,920	2.79	3.22	50	6.47	3.25
.....	48,700	8,060	18,840	1.95	2.18	48	4.56	2.38
.....	26,680	4,900	10,720	1.11	1.28	34	3.82	2.54
.....	20,440	4,080	8,337	.864	.996	16	6.23	5.23
.....	28,000	3,680	7,636	.791	.882	28	3.15	2.27
.....	12,040	2,600	4,303	.446	.514	90	.57	.06
.....	19,840	2,280	4,648	.481	.537	22	2.50	1.96
.....	130,700	4,480	25,610	2.65	3.06	54	5.71	2.65
ear.....	150,600	1,760	14,100	1.46	19.90	44	44.93	25.03
.....	75,110	7,580	17,520	1.81	2.09	75	2.78	.69
.....	203,800	9,020	32,520	3.37	3.51	90	3.88	.37
.....	218,700	14,700	54,410	5.64	6.50	149	4.35	—2.15
.....	108,700	7,750	28,760	2.99	3.34	104	3.20	—.14
.....	9,530	4,670	5,973	.619	.714	36	1.97	1.26
.....	4,330	2,530	3,186	.330	.368	11	3.45	3.08
.....	4,330	2,000	3,086	.320	.369	13	2.75	2.38
.....	4,330	1,515	2,464	.255	.294	13	2.16	1.87
.....	2,000	1,295	1,490	.154	.172	8	2.01	1.84
.....	5,380	1,515	2,767	.287	.331	10	3.36	3.03
.....	11,470	1,750	2,837	.294	.328	13	2.49	2.16
.....	54,780	7,330	18,970	1.96	2.26	50	4.50	2.24
ear.....	218,700	1,295	14,500	1.50	20.28	55	36.90	16.62

es April 16, 1901, to September 1, 1902, liable to some error on account of uncertainty of the

: February 11-23, 1902; no correction made in estimates.

Estimated monthly discharge of Potomac River at Point of Rocks, Md.—Contin

Month.	Discharge in second-feet.			Run-off.			Precipi
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.
1903.							
January	68,880	6,520	17,200	1.78	2.05	58	3.51
February	49,160	12,490	22,190	2.30	2.40	69	3.49
March	99,590	9,070	26,730	2.77	3.19	89	3.59
April	97,930	9,530	28,900	2.99	3.34	89	3.75
May	9,070	4,330	6,212	.643	.741	25	2.92
June	73,860	6,520	17,970	1.86	2.08	32	6.57
July	45,260	4,330	12,760	1.32	1.52	33	4.67
August	8,620	2,810	4,826	.500	.576	16	3.67
September	16,850	2,530	4,669	484	.540	24	2.29
October	6,130	2,000	3,212	.333	.384	15	2.57
November	2,810	2,000	2,175	.225	.251	27	.91
December[a]	4,010	2,000	2,926	.303	.349	45	.78
The year	99,590	2,000	12,480	1.29	17.42	45	38.72
1904.							
January[b]	35,620	3,400	7,287	.755	.870	42	2.05
February[b]	37,060	8,620	17,480	1.81	1.95	163	1.20
March	22,300	5,380	11,170	1.16	1.34	64	2.08
April	28,120	3,400	7,406	.767	.856	25	2.46
May	27,460	5,380	9,362	.970	1.12	33	3.43
June	38,500	3,100	10,160	1.05	1.17	24	4.78
July	10,970	2,530	4,510	.467	.538	12	4.54
August	3,400	1,750	2,394	.248	.286	12	2.32
September	2,000	1,295	1,592	.165	.184	8	2.25
October	2,000	900	1,164	.121	.140	8	1.66
November	1,515	1,090	1,340	.139	.155	19	.79
December	5,020	1,515	2,201	.228	.263	10	2.52
The year	38,500	900	6,339	.657	8.87	30	30.08
1905.							
January[c]	17,430	4,670	8,626	.894	1.03	33	3.12
February	6,520	5,020	5,625	.583	.607	35	1.73
March	63,900	6,520	23,480	2.43	2.80	97	2.89
April	10,000	4,010	6,581	.682	.761	44	1.72
May	9,070	2,810	4,493	.465	.536	18	3.05
June	32,820	2,810	6,579	.681	.760	15	5.23
July	22,300	3,400	10,190	1.06	1.22	18	6.63
August	13,530	2,810	5,830	.604	.696	17	4.08
September	5,750	2,000	3,205	.332	.370	20	1.86
October	5,380	1,750	2,888	.299	.345	10	3.47
November	3,700	1,750	2,267	.235	.262	21	1.22
December	37,060	3,400	10,640	1.10	1.27	36	3.52
The year	63,900	1,750	7,534	.780	10.66	28	38.52
1906.							
January	44,500	8,180	14,990	1.55	1.79		
February	9,070	3,700	5,116	.530	.552		
March	79,670	4,330	15,900	1.65	1.90		
April	64,730	8,180	22,440	2.33	2.60		
May	10,480	2,810	5,538	.574	.662		
June	19,820	3,400	7,007	.726	.810		
July	8,620	2,530	4,381	.454	.523		
August	37,060	3,400	15,200	1.58	1.82		
September	12,490	2,530	4,275	.444	.495		
October	106,200	2,530	16,310	1.69	1.95		
November	15,150	4,010	6,341	.657	.733		
December	55,600	4,010	11,000	1.14	1.31		
The year	106,200	2,530	10,710	1.11	15.14		

[a] Ice conditions December 17–31, 1903; no correction made in estimates.
[b] Ice conditions during portions of January and February, 1904; no correction made in est
[c] Ice gorge January 27, 1905: no correction made in estimate.

The following table gives the horsepower, 80 per cent efficien foot of fall, that may be developed at different rates of dischar shows the number of days on which the flow and the corresp

:sepower were respectively less than the amounts given in the col-ıns for "discharge" and "horsepower."

charge and horsepower table for Potomac River at Point of Rocks, Md., from 1895 to 1906.

Discharge in second-feet.	Horsepower 80 per cent efficiency per foot fall.	Days of deficient flow.											
		1895. [a]	1896. [b]	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	1906.
990	90	.....	.....	.....	.....	.....	.....	.....	.....	.....	6	.....	.....
1,100	100	5	.....	.....	.....	.....	3	.....	.....	.....	23	.....	.....
1,320	120	40	14	.....	.....	.....	39	.....	12	.....	58	.....	.....
1,540	140	79	28	3	.....	.....	78	.....	25	.....	86	.....	.....
1,760	160	107	43	9	6	23	101	.....	51	.....	107	14	.....
1,980	180	124	60	29	8	50	110	2	51	.....	107	14	.....
2,200	200	128	72	56	29	82	115	5	83	22	126	32	.....
2,750	250	150	101	98	59	133	140	49	109	59	140	46	9
3,300	300	162	130	107	71	152	152	60	142	74	161	90	28
3,850	350	182	162	137	95	172	173	88	162	103	196	130	59
4,400	400	190	187	162	106	176	198	101	175	128	207	149	106
4,950	450	201	222	186	128	188	223	126	185	139	210	162	128
5,500	500	208	238	195	136	197	233	133	195	161	223	195	151

[a] February 17 to December 31, 1895.
[b] Miss ng days estimated from Millville records.

NOTE.—The minimum flow dur:ng the period covered by the above table was 900 second-feet, giving horsepower per foot of fall for two three-day periods during October, 1904.

MONOCACY RIVER NEAR FREDERICK, MD.

Monocacy River rises in Adams County, Pa., flows somewhat west south, and enters Potomac River in the southeastern part of Fred-ick County, Md. Its length below the confluence of Rock and ırsh creeks is 55 miles. Its drainage area is 940 square miles. It s a number of tributaries on which small mills are located.

The gaging station was established August 4, 1896, by E. G. Paul. is located at the county bridge on the toll road leading from Fred-ck to Mount Pleasant, Md. It is 4 miles northeast of Frederick, ɔut 2,000 feet above the mouth of Israel Creek and 3,000 feet ow the mouth of Tuscarora Creek.

The channel is straight for 300 feet above and 100 feet below the dge. Both banks are low, liable to overflow, and covered with a ıge of trees, but all water passes beneath the bridge. The bed is mposed of gravel and cobblestones, except near the banks, where it :omposed of silt and is subject to change.

Discharge measurements are made from the two-span highway dge, which has a total span of 310 feet. The channel at this point ɔivided by a small, low island, which serves as a foundation for the :r of the bridge. The right channel is measured from the lower and ɜ left from the upper side of the bridge, as the results are better ɜn would be furnished by a continuous section on either side of the idge. The pier and island obstruct the flow to some extent, causing

dead water for 20 feet to the right of the pier at low water and eddies at high water. The initial point for soundings is a crosscut in the face of the parapet wall on the lower wing of the right abutment.

September 3, 1902, the original wire gage was replaced by a standard chain gage which is located in the middle of the first span from the right bank and is attached to the bridge floor on the lower side of the bridge. The length of the chain from the end of the weight to the marker is 35.04 feet. The gage is read twice each day by E. L. Derr. The bench mark is a hole drilled in the top of a coping stone on the lower wing of the right abutment, about 100 feet back from the initial point for soundings. Its elevation is 29.17 feet above gage datum. On October 31, 1905, the elevation of the top of the pulley was found to be 25.47 feet above gage datum.

Estimates published for 1896 to 1903 have been revised; 1904 and 1905 estimates, as previously published, have not been changed. Two rating curves have been used to determine the discharge of the river. The estimates are probably well within 10 per cent of the true discharge for normal conditions of flow. Owing to gorging below the bridge at high stages, the tangent has been considered to give the best results above gage height 12.0 feet. Ice conditions probably affect the discharge to a considerable extent.

A summary of the records gives the following results: Maximum discharge for twenty-four hours, 20,460 second-feet; minimum discharge for twenty-four hours, 49 second-feet; mean annual discharge for ten years, 1,130 second-feet; mean annual rainfall for ten years, 45.04 inches.

Discharge measurements of Monocacy River near Frederick, Md.

Date.	Gage height.	Discharge.
1896.	*Feet.*	*Second-feet.*
August 5	4.10	176
September 16	3.80	88
November 19	4.20	206
1897.		
February 9	6.00	1,019
February 24	8.95	3,569
March 9	6.00	1,085
April 10	7.55	2,264
July 3	4.30	220
September 3	4.15	182
October 20[a]	4.05	122
1898.		
January 26	7.55	2,342
August 20	6.95	1,605
1899.		
May 22	5.20	633
September 6	4.00	153
1900.		
June 29	4.10	191
September 20	3.80	88
1901.		
July 31	4.10	179
1901 Continued.		
December 28	6.30	1,26
1902.		
September 4	3.74	100
1903.		
March 13	6.49	1,282
April 17	11.03	4,708
April 18	9.40	3,733
September 14	4.60	336
November 10	4.32	212
1904.		
July 12	5.18	475
September 26	3.96	100
October 20[b]	3.92	98
1905.		
March 11	10.13	4,65[illegible]
March 12	9.73	4,25[illegible]
June 21	4.16	17[illegible]
October 31	4.68	31[illegible]
1906.		
May 31	4.70	3[illegible]

[a] *Measurement made at mouth of river.*

[b] Measurement made above bridge by wading.

Daily gage height, in feet, of Monocacy River near Frederick, Md.

y.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
6.						1896.					
.....	.....	3.6	4.8	3.9	4.8	17.....	3.8	3.9	4.0	4.2	4.0
.....	.....	3.6	4.4	4.0	4.5	18.....	4.4	3.9	3.9	4.2	4.0
.....	.....	3.6	4.1	4.0	4.5	19.....	4.15	4.0	3.9	4.2	4.0
.....	4.1	3.6	4.0	4.0	4.3	20.....	3.9	4.0	3.8	4.2	4.0
.....	4.1	3.6	3.9	5.45	4.3	21.....	3.9	4.0	3.9	4.2	4.0
.....	4.0	3.7	3.9	7.5	4.1	22.....	3.9	3.9	3.9	4.0	3.9
.....	4.0	3.8	3.9	5.0	4.1	23.....	3.8	3.9	3.9	4.0	3.9
.....	3.9	3.9	3.9	4.5	4.1	24.....	3.7	3.8	3.9	4.0	4.1
.....	3.9	3.9	3.9	4.5	4.2	25.....	3.7	3.9	3.9	4.0	4.2
.....	3.9	3.8	3.9	4.8	4.2	26.....	3.9	3.8	3.9	4.0	4.1
.....	3.8	3.7	3.8	4.5	4.3	27.....	3.9	3.8	3.9	4.0	4.1
.....	3.9	3.7	3.8	4.5	4.2	28.....	3.8	3.8	3.9	4.0	4.1
.....	3.9	3.7	3.9	4.3	4.1	29.....	3.7	3.8	3.9	4.35	4.0
.....	3.9	3.7	4.2	4.3	4.1	30.....	3.6	5.0	3.9	5.2	4.0
.....	3.9	3.7	4.1	4.2	4.1	31.....	3.7	.....	3.9	.....	4.2
.....	3.8	3.75	4.1	4.2	4.1						

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
....	4.2	4.4	5.7	5.0	4.6	5.0	4.2	4.9	4.15	3.95	4.15	5.25
....	4.2	4.4	5.5	5.0	6.3	4.8	4.2	4.7	4.05	3.95	14.85	5.15
....	4.2	5.0	5.6	4.9	6.2	4.7	4.3	4.5	4.15	3.85	8.15	5.15
....	4.2	6.0	7.5	4.9	6.2	5.0	4.2	4.4	4.05	3.85	6.55	8.15
....	4.2	5.5	7.5	6.9	6.0	7.5	4.2	4.4	4.05	3.75	5.35	12.4
....	4.3	8.4	8.0	5.9	5.9	5.6	4.2	4.3	3.95	3.85	5.05	8.65
....	4.3	15.0	7.6	5.6	5.6	5.4	4.2	4.3	3.95	3.75	4.85	7.2
....	4.5	8.45	6.2	5.4	5.4	4.95	4.2	4.2	3.95	3.75	4.75	6.55
....	4.4	6.0	6.0	9.3	5.1	6.15	4.9	4.2	3.95	3.75	5.55	5.95
....	4.3	5.6	6.5	8.55	5.0	5.8	4.5	4.2	3.95	3.85	5.55	5.75
....	4.2	5.2	6.2	6.55	5.1	5.3	4.2	10.6	3.95	3.85	4.85	5.55
....	4.3	5.2	5.8	6.6	5.1	5.0	4.2	8.5	3.95	3.85	4.75	6.85
....	4.3	4.9	5.8	5.7	15.6	4.9	7.0	5.45	3.95	4.25	4.65	6.65
....	4.3	4.6	5.7	5.8	15.6	4.7	5.2	4.45	3.85	4.15	4.55	10.65
....	4.0	4.6	5.7	5.9	10.9	4.7	4.6	4.25	3.85	4.05	5.15	14.6
....	4.0	5.7	5.8	6.2	7.4	4.7	4.3	5.35	3.85	3.95	5.55	13.85
....	4.0	7.4	5.4	5.8	6.8	4.8	4.3	4.85	4.45	3.95	4.95	7.15
....	4.0	7.4	6.6	5.8	6.5	4.8	5.1	4.3	4.45	3.85	4.75	6.65
....	4.3	6.7	7.0	5.5	6.1	4.7	4.95	4.1	4.05	3.75	4.65	6.15
....	4.7	6.1	9.8	5.3	5.8	4.7	5.25	4.1	3.85	3.75	4.55	5.95
....	4.5	5.7	7.6	5.1	5.9	4.9	4.95	4.1	3.85	3.85	4.65	5.85
....	5.5	12.1	6.6	5.0	6.0	4.7	6.4	5.5	3.95	3.95	4.55	6.55
....	5.4	14.6	6.5	5.0	5.5	4.5	5.65	4.8	3.95	3.95	4.75	6.05
....	4.8	8.85	7.4	5.0	5.3	4.5	4.95	16.2	5.65	3.95	5.6	5.65
....	5.2	8.3	7.3	4.9	6.7	4.4	4.45	6.75	5.15	4.05	4.85	5.15
....	5.0	7.0	6.1	4.9	6.0	4.4	4.35	5.75	4.65	4.35	6.55	5.55
....	5.0	6.5	5.8	4.9	5.3	4.4	7.7	5.1	3.95	4.25	7.05	5.45
....	5.0	6.0	5.6	4.8	5.2	4.4	9.9	4.7	3.95	4.15	6.55	5.45
....	5.0	.....	5.4	4.7	5.0	4.2	7.8	4.35	3.95	4.05	5.85	5.35
....	4.8	.....	5.3	4.6	4.9	4.2	6.1	4.15	3.95	4.05	5.65	5.35
....	4.5	.....	5.2	.....	5.0	.....	5.3	4.15	.....	3.95	.....	5.45

ozen at the gage January 25 to February 2 1897. All gage heights from July 3 to December liable to errors of one or two tenths owing to incorrect wire length.

Daily gage height, in feet, of Monocacy River near Frederick, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898.[a]												
1	5.25	5.4	5.4	7.1	4.7	5.5	4.4	4.7	4.0	3.8	5.5	6.1
2	4.85	6.5	5.3	6.9	4.7	5.4	4.3	4.6	4.0	3.8	5.3	6.2
3	5.65	6.5	5.3	6.0	4.6	5.3	4.3	4.4	4.0	3.8	4.7	5.5
4	5.35	6.5	5.7	5.8	4.6	5.2	4.3	4.1	4.0	3.8	4.6	7.0
5	5.15	6.1	6.2	5.8	4.6	5.1	4.4	7.65	3.9	3.8	4.5	17.8
6	5.15	6.1	6.0	5.8	4.6	5.1	4.4	6.9	3.9	3.8	4.4	8.5
7	5.15	5.5	5.9	5.8	6.2	5.1	4.4	5.1	3.9	3.8	4.4	7.0
8	5.25	5.0	5.5	5.5	8.25	5.0	4.4	4.2	4.0	3.9	4.4	6.4
9	5.35	5.2	5.3	5.5	13.4	5.0	4.4	4.1	4.0	3.9	4.4	5.7
10	6.15	5.4	5.2	5.2	7.5	5.0	4.4	6.7	4.0	3.8	4.7	5.5
11	6.75	5.4	5.2	5.2	6.5	5.0	4.3	12.4	3.9	3.8	9.7	5.3
12	6.85	6.0	5.1	5.2	6.5	5.0	4.2	6.0	3.8	3.9	6.9	5.3
13	7.75	6.2	5.1	5.1	8.2	5.0	4.2	5.4	3.8	3.8	5.4	5.3
14	8.15	5.6	5.1	5.1	6.0	4.9	4.2	5.4	3.8	3.8	5.3	5.3
15	11.55	5.5	5.0	5.3	5.6	4.9	4.2	4.6	3.8	4.0	5.2	5.3
16	11.05	5.3	5.0	5.9	6.75	4.8	4.1	4.5	3.8	4.2	5.0	5.0
17	8.4	5.2	5.0	5.5	11.55	4.7	4.1	4.5	3.8	3.9	5.5	5.0
18	7.15	5.1	5.0	5.0	7.5	4.6	4.1	6.35	3.8	5.5	6.1	5.0
19	6.55	6.4	5.0	4.9	6.5	4.5	4.1	10.1	3.8	6.5	12.35	6.0
20	6.55	6.5	4.9	4.9	6.5	4.5	4.3	7.0	3.8	5.6	9.5	9.6
21	8.65	14.8	6.1	4.9	6.4	4.5	5.4	5.5	3.8	4.9	6.85	8.6
22	9.15	12.0	7.3	4.8	6.0	4.5	4.4	4.9	3.9	11.55	5.9	8.3
23	12.4	7.5	7.6	4.8	6.0	4.5	4.1	4.6	4.15	9.0	5.9	13.6
24	9.15	6.5	7.6	5.0	6.6	4.4	4.0	4.5	4.2	7.1	6.3	8.0
25	7.15	6.3	10.75	5.3	6.7	4.4	3.9	4.4	4.1	5.2	5.9	7.5
26	8.5	5.7	8.5	5.3	6.6	4.4	3.9	4.3	3.9	5.2	5.4	6.1
27	8.0	5.6	6.6	5.0	6.3	4.4	4.3	4.3	3.9	5.5	5.2	6.0
28	7.3	5.4	6.6	4.9	5.9	4.4	4.3	4.2	3.9	5.3	5.2	5.9
29	6.5	.....	7.7	4.9	5.8	4.4	4.3	4.1	3.9	5.1	5.3	5.5
30	5.9	.....	9.5	4.8	5.7	4.4	4.2	4.1	3.8	5.1	5.7	5.5
31	5.7	.....	7.9	.....	5.6	.....	4.0	4.0	.....	6.0	.....	5.5
1899.[b]												
1	5.4	5.2	11.5	7.1	4.8	7.1	4.1	3.9	4.3	4.0	7.3	4.1
2	5.0	5.2	10.1	6.9	4.8	11.1	4.1	4.0	4.3	3.9	6.4	4.1
3	5.5	5.8	9.2	6.5	5.0	7.05	4.1	5.1	5.4	3.9	6.3	4.1
4	6.0	5.6	8.7	6.1	4.9	5.2	4.0	5.0	5.0	3.9	6.0	4.1
5	6.3	5.9	17.2	6.0	4.9	4.9	4.0	5.0	4.5	3.8	5.3	4.1
6	12.75	5.7	11.45	6.0	4.8	4.7	4.5	4.9	4.0	3.8	5.0	4.0
7	14.85	5.5	8.9	7.6	4.8	4.5	4.4	4.5	3.9	3.9	4.5	4.0
8	12.5	5.4	7.8	12.6	5.2	4.5	4.2	4.0	3.8	3.9	4.4	3.9
9	10.2	6.0	7.5	7.8	6.6	5.5	4.3	4.0	3.7	4.1	4.3	3.9
10	6.1	6.0	7.4	6.9	5.6	6.85	4.2	4.0	4.0	4.1	4.3	3.9
11	6.1	6.0	7.4	6.5	5.4	6.9	4.2	4.0	4.0	4.0	4.2	3.9
12	5.7	6.0	7.3	6.2	5.8	6.5	4.1	4.2	3.9	4.0	4.1	4.8
13	5.8	6.0	7.1	5.9	5.4	5.2	4.3	4.0	3.9	3.9	4.1	5.95
14	6.0	6.0	6.5	5.6	5.0	4.9	4.2	3.9	3.8	3.9	4.1	5.5
15	6.8	6.0	6.5	5.6	5.0	6.2	4.2	3.9	3.8	3.9	4.1	4.5
16	6.6	6.0	9.7	5.6	4.9	5.1	4.5	3.9	3.8	3.9	4.1	4.4
17	6.6	6.2	6.9	5.6	5.2	4.8	4.3	3.9	3.7	3.9	4.1	4.4
18	7.1	6.8	7.9	5.6	6.5	4.5	4.3	3.8	3.7	4.0	4.1	4.3
19	6.4	7.9	13.9	5.6	7.7	4.4	4.2	3.8	3.7	3.9	4.1	4.2
20	5.6	9.0	10.1	5.4	6.9	4.4	4.1	3.8	6.0	3.9	4.1	4.2
21	5.6	12.5	7.9	5.2	6.3	4.4	4.0	3.8	5.3	3.8	4.1	4.5
22	5.6	13.5	7.8	5.1	5.2	4.3	3.9	3.8	5.0	3.8	4.1	4.4
23	5.6	15.65	7.6	5.1	5.2	4.3	3.9	3.8	4.9	3.8	4.1	4.3
24	5.7	11.6	7.2	5.0	5.0	4.3	5.9	3.8	4.5	3.8	5.3	7.1
25	10.4	9.1	6.7	5.0	4.9	4.2	4.3	3.8	4.3	3.8	4.7	6.9
26	8.2	9.1	6.7	5.0	4.8	4.2	4.5	3.8	5.25	3.8	4.4	6.2
27	6.5	17.8	6.7	5.0	4.7	4.2	4.4	4.7	5.5	3.8	4.3	6.0
28	5.2	12.5	10.15	4.9	4.7	4.2	4.3	4.95	5.3	3.8	4.3	5.1
29	5.2	.....	11.0	4.9	4.6	4.2	4.2	4.7	5.0	3.8	4.3	a 5.1
30	5.2	.....	8.1	4.8	5.0	4.2	4.0	4.3	4.5	3.8	4.2	a 5.1
31	5.2	.....	7.9	.....	5.0	.....	3.9	4.3	.....	5.0	.....	a 5.4

[a] River frozen February 2–9, 1898.
[b] River frozen at the gage January 2, February 9–21, and December 28–31, 1899.

aily gage height, in feet, of Monocacy River near Frederick, Md.—Continued.

y.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
).[a]												
.....	5.4	5.1	13.45	6.4	4.7	4.4	4.0	3.95	3.85	3.9	3.7	5.2
.....	5.4	5.1	12.0	5.7	4.7	4.4	4.0	3.85	3.75	3.8	3.7	4.3
.....	5.4	5.1	9.5	5.5	4.7	4.4	3.9	3.85	3.75	3.8	3.7	4.3
.....	5.2	5.1	8.2	5.5	4.9	4.4	3.9	3.75	3.6	3.8	4.1	7.2
.....	5.0	5.2	7.3	5.5	4.8	4.4	3.9	3.65	3.6	3.8	4.1	12.1
.....	4.9	5.1	7.1	5.4	4.6	4.3	3.9	3.65	3.65	3.7	4.0	6.0
.....	4.8	5.3	8.0	5.3	4.5	4.2	3.8	3.65	3.65	3.7	4.0	5.5
.....	4.5	6.9	7.5	5.2	4.4	4.2	3.8	3.65	3.65	3.7	4.0	5.2
.....	4.5	7.55	6.5	5.1	4.4	4.2	3.7	3.65	3.6	3.7	3.9	4.9
.....	4.9	6.9	6.3	5.1	4.4	4.1	3.7	3.65	3.6	3.7	3.9	4.5
.....	5.0	5.3	6.3	5.0	4.4	4.1	3.7	3.55	3.55	3.7	3.9	4.3
.....	10.2	5.5	5.9	5.0	4.4	4.1	3.7	3.55	3.55	3.7	3.9	4.2
.....	9.2	15.1	5.7	5.0	4.3	4.1	3.7	3.45	3.55	3.7	3.9	4.0
.....	5.4	12.85	5.6	5.0	4.3	4.1	3.7	3.45	3.5	3.9	3.9	4.0
.....	4.9	7.0	5.5	5.0	4.3	4.4	3.7	3.45	3.5	4.1	3.9	4.0
.....	4.8	6.5	5.4	4.9	4.3	4.8	3.6	3.45	3.85	4.1	3.9	4.0
.....	4.6	5.9	5.4	4.9	4.3	5.0	3.6	3.55	3.85	4.1	3.9	4.0
.....	4.6	5.9	5.4	5.1	4.3	5.8	3.6	3.85	3.85	3.9	3.8	4.0
.....	4.9	5.8	5.4	5.2	6.5	6.0	3.7	3.75	3.8	3.8	3.8	3.9
.....	9.0	5.5	13.5	5.1	7.0	5.1	4.55	3.75	3.8	3.7	3.8	3.9
.....	9.5	5.5	10.2	5.0	6.5	4.9	4.55	3.75	3.8	3.7	3.8	3.9
.....	7.05	20.8	9.1	5.0	5.9	4.5	3.75	4.75	3.7	3.7	3.8	4.0
.....	6.5	15.0	8.2	5.5	4.9	4.4	4.05	4.65	3.65	3.8	3.9	4.0
.....	6.0	10.5	6.5	5.6	4.8	4.2	5.45	4.05	3.5	3.8	3.9	4.1
.....	5.7	8.5	6.1	5.4	4.7	4.2	4.75	4.05	3.5	3.8	3.9	4.1
.....	5.5	7.1	6.0	4.9	4.6	4.2	4.15	3.95	3.5	3.7	9.2	4.1
.....	5.1	6.5	5.9	4.8	4.5	4.2	4.15	3.85	3.5	3.7	7.3	4.1
.....	4.9	6.5	5.7	4.8	4.5	4.1	4.05	5.45	3.6	3.7	7.1	4.1
.....	4.6	.....	5.5	4.8	4.5	4.1	3.95	5.25	.....	3.7	6.9	4.0
.....	4.5	.....	5.5	4.7	4.5	4.0	3.95	4.25	4.0	3.7	6.3	4.0
.....	4.5	.....	6.5	.....	4.5	.....	3.95	3.95	.....	3.7	.....	4.5
..[b]												
.....	4.4	4.6	4.5	5.7	5.9	6.0	4.3	4.1	4.3	5.2	4.2	4.9
.....	4.2	4.4	4.5	5.6	5.8	5.6	4.3	4.0	4.9	5.1	4.2	4.7
.....	4.2	4.4	4.4	18.0	5.6	5.4	4.2	4.0	4.5	4.9	4.2	4.9
.....	4.3	4.4	5.0	15.5	5.4	5.3	4.2	4.0	4.4	4.8	4.2	4.9
.....	4.3	4.8	5.5	10.5	5.3	5.3	4.2	4.0	4.3	4.6	4.2	4.9
.....	4.2	4.8	5.3	7.9	5.2	5.0	4.4	5.4	4.3	4.4	4.2	4.9
.....	4.1	4.7	5.0	8.3	5.1	5.5	4.3	7.1	4.3	4.3	4.2	4.8
.....	4.0	4.6	5.0	7.2	5.1	7.1	4.3	6.0	4.3	4.3	4.3	4.8
.....	4.1	4.5	5.1	6.5	5.1	5.4	4.2	4.7	4.3	4.2	4.3	4.8
.....	4.1	4.5	5.5	6.2	5.5	5.2	4.1	4.6	4.2	4.2	4.3	7.5
.....	5.5	4.5	20.5	5.9	5.5	4.9	4.1	4.2	4.2	4.2	4.3	6.5
.....	7.6	4.5	11.9	5.6	5.4	4.9	5.1	4.1	4.2	4.1	4.3	6.1
.....	6.9	4.4	8.0	5.6	5.3	8.0	5.5	4.6	4.2	4.1	4.3	5.3
.....	6.4	4.3	7.3	5.4	5.1	6.4	4.8	4.4	4.2	4.8	4.3	5.4
.....	5.9	4.3	6.9	6.9	4.9	6.75	4.8	4.3	4.2	5.0	4.3	19.75
.....	4.9	4.3	6.1	6.5	4.9	7.45	4.9	5.6	5.5	4.9	4.3	9.5
.....	4.8	4.3	5.9	6.3	4.9	7.2	5.0	4.9	4.7	4.8	4.2	7.1
.....	4.7	4.3	5.8	5.9	4.9	6.1	4.9	5.1	4.5	4.4	4.2	6.9
.....	4.7	4.4	5.6	5.5	4.85	5.9	5.2	4.5	4.5	4.2	4.2	6.5
.....	4.5	4.9	5.3	9.6	4.8	5.4	5.1	6.4	4.4	4.2	4.2	6.2
.....	4.3	5.0	10.5	14.6	4.8	5.2	5.1	6.1	4.3	4.1	4.2	6.0
.....	4.3	5.1	7.6	9.6	4.8	5.2	4.9	5.2	4.3	4.1	4.2	5.9
.....	4.2	5.0	7.1	8.1	11.3	5.1	4.5	4.5	4.2	4.1	4.5	5.9
.....	4.2	5.0	6.0	8.5	9.1	4.9	4.4	4.6	4.1	4.1	9.4	5.7
.....	4.2	4.9	6.0	7.9	7.9	4.7	4.2	5.0	4.1	4.1	7.5	5.5
.....	4.3	4.8	6.1	7.3	7.1	4.6	4.2	4.9	4.1	4.2	5.9	5.5
.....	4.3	4.6	13.55	6.9	9.0	4.5	4.5	4.5	4.1	4.2	5.5	7.35
.....	4.3	4.5	10.4	6.4	9.2	4.5	4.3	4.3	4.1	4.2	5.3	6.5
.....	4.8	.....	7.4	6.1	11.5	4.5	4.2	4.2	4.7	4.2	5.1	13.25
.....	4.7	.....	5.9	6.0	9.1	4.5	4.2	4.2	6.7	4.2	5.0	18.5
.....	4.7	.....	5.8	.....	8.6	.....	4.1	4.2	.....	4.2	.....	12.5

[a] River frozen at the gage January 1–6 and February 1–4, 1900.
[b] No gage weight on the wire June 1–4, 1901; gage heights estimated by the observer.

Daily gage height, in feet, of Monocacy River near Frederick, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1902.[a]												
1	8.5	5.9	25.2	7.0	5.2	4.3	6.9	5.2	3.7	4.6	5.1	8.5
2	8.2	5.9	14.5	6.9	5.1	4.3	6.4	4.5	3.7	6.0	5.0	7.9
3	7.1	5.9	10.9	10.5	5.1	4.3	4.9	4.2	3.7	5.1	4.9	10.0
4	6.0	8.5	10.2	8.5	5.0	4.2	4.8	4.1	3.7	4.2	4.7	8.5
5	7.9	8.5	9.6	8.3	4.9	4.2	4.8	4.1	3.9	4.5	4.6	8.2
6	8.2	8.1	9.2	8.0	4.9	4.1	4.8	4.2	3.7	7.1	4.5	7.9
7	8.1	7.9	9.1	7.9	4.8	4.1	4.8	4.2	3.6	5.2	4.4	7.8
8	7.5	7.8	8.9	7.5	4.8	4.1	4.6	4.1	3.6	5.1	4.6	7.6
9	5.9	7.4	9.0	17.9	4.7	4.1	4.5	4.0	3.6	5.0	4.5	7.5
10	5.5	6.9	15.2	16.9	4.7	4.1	4.4	4.0	3.6	4.9	4.5	7.4
11	5.4	6.5	15.5	8.2	4.7	4.1	4.3	4.0	3.6	5.5	4.5	7.9
12	5.4	6.5	12.2	7.5	4.6	4.0	4.2	4.0	3.55	12.8	4.4	9.2
13	5.3	6.5	14.5	7.3	4.6	7.1	4.1	3.9	3.5	8.1	4.4	11.5
14	5.3	6.3	10.1	6.9	4.6	5.5	4.0	3.9	3.5	6.5	4.4	9.5
15	5.2	6.1	10.0	6.5	4.6	4.2	4.0	3.8	3.5	5.1	4.3	8.2
16	5.1	5.9	9.5	6.3	4.6	4.2	3.9	3.8	3.5	4.9	4.2	15.5
17	4.9	5.9	14.6	6.1	4.5	4.2	3.9	3.8	3.5	4.7	4.2	14.5
18	4.9	5.9	10.2	5.9	4.5	4.1	3.9	3.8	3.5	4.6	4.2	8.5
19	4.9	5.9	8.4	5.8	4.5	4.1	4.1	3.8	3.5	4.5	4.6	8.2
20	4.9	6.1	8.1	5.7	4.5	4.1	4.1	3.8	3.6	4.4	4.5	9.5
21	7.2	10.2	7.9	5.6	4.5	4.2	5.2	3.7	3.6	4.3	4.4	10.2
22	18.05	14.4	7.4	5.5	4.5	4.2	4.3	3.7	3.6	4.2	4.3	17.2
23	7.1	9.6	7.1	5.4	4.5	4.1	4.2	3.7	3.5	4.2	4.2	14.2
24	6.9	9.4	6.9	5.3	4.4	4.1	4.1	3.6	3.5	4.2	4.2	8.2
25	6.1	10.5	6.5	5.3	4.4	4.1	4.1	3.6	3.8	4.1	4.2	7.7
26	6.9	24.0	6.3	5.2	4.4	5.9	4.0	3.6	4.0	4.1	5.9	7.5
27	11.15	21.4	6.0	5.1	4.5	5.6	4.0	3.6	9.1	4.1	9.4	7.4
28	7.5	19.35	6.0	5.0	4.5	5.1	3.9	4.1	5.1	13.7	7.9	7.3
29	6.9	.....	5.9	5.2	4.4	4.5	3.9	3.9	4.9	9.5	5.9	7.2
30	6.5	.....	5.6	5.2	4.3	4.5	4.5	3.7	4.8	5.5	5.9	7.1
31	6.2	.....	6.2	.....	4.3	.....	5.5	3.7	.....	5.3	.....	7.0
1903.[b]												
1	5.5	7.6	21.4	7.9	5.6	6.5	9.5	5.3	6.5	4.4	4.3	
2	15.8	7.3	9.5	7.4	5.5	6.4	8.1	5.1	5.9	4.4	4.3	
3	13.35	8.3	8.1	6.9	5.5	6.1	7.5	4.9	5.5	4.3	4.3	
4	10.5	16.35	7.9	7.9	5.5	5.1	8.1	4.9	5.4	4.3	4.3	
5	9.5	10.5	7.5	7.2	5.4	4.9	11.5	4.9	5.2	4.3	4.3	
6	8.2	7.9	7.2	6.5	5.3	4.9	9.5	4.9	5.0	4.3	4.3	
7	7.3	7.5	6.9	6.9	5.3	5.8	7.3	5.4	4.9	4.4	4.3	
8	6.9	7.3	7.5	7.5	5.3	5.8	6.2	5.2	4.8	5.2	4.3	
9	6.3	7.5	8.6	12.2	5.2	5.4	6.1	5.1	5.4	7.2	4.3	
10	6.9	6.9	7.4	7.9	5.1	5.1	5.9	4.9	7.2	5.2	4.3	
11	9.6	7.1	7.2	7.2	5.0	5.8	5.8	4.9	6.9	6.1	4.3	
12	9.3	10.5	7.1	6.7	4.9	8.1	9.15	4.8	5.5	5.9	4.3	
13	8.6	7.5	6.3	7.4	4.9	6.5	18.8	4.8	4.9	5.6	4.3	
14	8.4	7.3	6.2	19.3	4.8	6.2	8.5	4.7	4.7	5.2	4.3	
15	8.2	7.8	6.2	21.6	4.8	5.8	7.5	4.7	4.6	5.1	4.3	
16	8.2	11.2	6.2	20.4	4.7	5.4	6.8	7.5	4.6	4.9	4.3	
17	7.9	7.9	6.1	11.4	4.7	5.2	6.5	7.1	6.5	4.9	4.4	
18	7.3	7.4	5.9	9.4	4.8	5.6	8.2	6.2	11.1	5.5	4.9	
19	7.3	7.1	5.9	8.4	4.8	5.4	11.5	5.9	5.8	5.4	4.7	
20	7.2	6.9	5.8	7.9	4.7	6.05	6.9	5.7	5.2	5.2	4.5	
21	8.55	6.7	5.8	7.4	4.7	7.5	6.4	4.9	4.9	4.9	4.4	
22	11.7	6.4	9.4	7.1	4.7	6.4	6.2	4.7	4.8	4.7	4.3	
23	8.6	6.2	17.1	6.7	4.7	5.7	5.6	4.6	4.7	4.6	4.3	
24	7.1	6.2	18.2	6.5	6.5	6.3	5.4	4.5	4.7	4.6	4.3	
25	6.5	6.2	8.6	6.4	6.1	5.9	5.3	4.5	4.6	4.5	4.3	
26	6.3	6.2	7.9	6.2	5.4	5.6	5.2	4.8	4.5	4.5	4.3	
27	6.1	7.3	7.5	6.1	4.9	5.6	5.2	4.7	4.5	4.4	4.3	
28	9.8	21.2	7.1	5.9	4.9	5.6	5.1	10.5	4.4	4.4	4.2	
29	10.6	.....	6.5	5.7	4.8	21.2	5.1	12.1	4.4	4.4	4.2	
30	11.2	.....	9.5	5.7	14.8	14.9	5.4	7.9	4.4	4.3	4.2	
31	8.1	.....	13.9	.....	7.5	.....	5.4	7.4	.....	4.3	.....	

[a] River frozen at gage February 4-19, 1902. Observer estimated gage heights March 20 to April 1902, the gage being broken.

[b] River frozen at gage January 12-20, 1903.

y gage height, in feet, of Monocacy River near Frederick, Md.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	4.6	5.0	8.1	5.9	4.9	7.5	4.5	4.2	3.8	4.0	4.0	4.0
.....	4.9	4.9	7.5	7.2	4.8	6.4	4.3	4.9	3.8	4.0	4.0	4.0
.....	4.8	5.4	6.2	6.4	4.7	6.0	4.3	4.7	3.8	3.8	4.0	4.0
.....	5.5	4.9	6.2	5.5	4.8	5.3	4.2	4.5	3.8	3.8	4.0	4.0
.....	5.1	4.6	5.9	5.4	4.7	7.4	4.2	4.3	3.8	3.8	4.0	4.0
.....	4.9	4.7	6.0	5.5	4.8	7.0	4.2	4.0	3.9	3.8	4.0	4.0
.....	4.7	8.2	17.0	5.4	4.7	6.8	4.4	4.0	3.9	3.8	4.0	4.0
.....	4.6	14.15	17.2	5.6	5.0	5.7	6.2	4.2	3.9	3.8	4.0	4.0
.....	4.6	6.4	8.2	7.8	4.9	5.4	7.1	4.5	3.9	3.8	4.0	4.0
.....	4.6	6.1	6.5	7.2	5.7	5.2	8.2	4.5	4.9	3.8	4.2	4.2
.....	4.6	6.0	6.6	6.4	5.4	5.4	7.3	12.6	5.2	3.8	4.0	4.2
.....	4.6	5.4	7.0	5.9	4.8	5.1	6.1	5.6	4.9	3.8	4.0	4.2
.....	4.6	5.1	6.2	5.6	4.7	5.0	7.4	4.6	4.8	6.0	4.2	4.2
.....	4.6	4.9	5.9	5.4	4.8	4.7	6.4	4.2	4.8	5.4	4.4	4.2
.....	4.6	4.9	5.8	5.1	5.0	4.6	5.2	4.2	4.7	4.8	4.4	4.2
.....	4.6	5.0	5.6	5.2	5.0	4.6	4.2	4.1	4.7	4.0	4.2	4.2
.....	4.5	4.9	5.5	5.0	4.8	4.5	4.1	4.1	4.6	4.0	4.2	4.2
.....	4.5	4.9	5.6	4.9	4.9	4.6	4.1	4.0	4.6	3.8	4.2	4.2
.....	4.5	4.9	5.5	4.9	5.2	4.5	4.1	4.0	4.6	3.8	4.2	4.2
.....	4.5	4.9	5.8	4.8	5.2	9.8	4.0	4.2	5.6	3.8	4.2	4.2
.....	4.5	5.0	6.2	4.8	4.9	7.4	4.0	4.7	5.2	4.0	4.0	4.2
.....	4.5	13.75	6.5	4.6	4.8	5.9	4.0	4.7	4.9	5.0	4.0	4.2
.....	19.9	12.2	6.8	4.6	4.6	4.9	4.0	4.6	4.6	4.6	4.0	4.2
.....	11.5	9.0	6.2	4.7	4.6	4.5	5.1	4.5	4.4	4.4	4.0	4.4
.....	6.1	6.8	5.9	4.6	4.4	4.4	5.1	4.2	3.9	4.2	4.0	4.6
.....	5.9	5.2	5.7	4.8	4.5	4.3	5.1	4.2	4.0	4.0	4.0	5.4
.....	4.6	4.9	5.7	4.9	4.4	4.1	5.1	4.1	4.2	4.0	4.0	6.8
.....	4.6	4.8	5.4	5.3	4.5	4.2	5.0	3.9	4.4	4.0	4.0	9.4
.....	5.5	4.8	5.2	5.3	4.3	4.2	4.9	3.8	4.2	4.0	4.0	9.2
.....	6.1	.....	5.2	5.1	4.4	4.3	4.4	3.8	4.0	4.0	4.0	7.8
.....	5.9	.....	5.4	.....	4.5	.....	4.2	3.8	.....	4.0	.....	5.8
.....	6.0	5.2	5.8	6.0	4.8	4.6	4.5	5.7	5.0	4.2	4.7	8.1
.....	6.4	5.0	5.8	5.8	4.8	4.4	5.2	5.1	4.9	4.1	4.7	7.2
.....	6.8	5.0	5.4	5.6	4.8	4.4	4.9	4.9	7.5	4.2	4.7	9.5
.....	6.4	4.8	5.2	5.4	4.6	4.4	4.6	4.7	6.4	5.0	4.6	9.
.....	6.2	4.8	6.6	6.4	4.6	4.2	4.5	4.6	6.1	4.5	4.6	8.3
.....	6.2	4.8	6.8	6.4	4.6	4.2	8.0	4.5	5.9	4.3	4.6	6.1
.....	17.4	4.8	7.4	6.2	4.6	4.6	7.9	4.4	5.1	4.4	4.6	5.6
.....	9.8	4.8	7.4	5.8	4.6	7.4	7.6	4.5	5.1	4.2	4.5	5.5
.....	7.2	4.8	10.9	5.6	4.6	7.2	6.5	4.5	4.9	4.3	4.5	5.4
.....	6.8	4.8	14.6	5.4	4.6	5.6	5.6	4.5	4.8	4.3	4.4	5.3
.....	6.6	4.8	11.8	7.6	4.4	4.4	4.9	4.5	4.9	4.4	4.4	5.1
.....	6.4	4.8	9.8	6.8	4.4	4.9	4.9	4.5	7.2	6.7	4.4	5.0
.....	6.4	4.8	9.0	6.4	4.4	8.3	4.9	5.8	5.5	6.1	4.4	5.0
.....	6.2	4.8	8.8	6.0	4.8	6.0	6.1	6.1	5.1	5.9	4.4	5.0
.....	5.8	4.8	8.2	5.8	5.0	5.2	10.6	5.5	4.9	5.3	4.3	4.9
.....	5.8	4.8	8.2	5.6	4.8	4.8	7.9	5.4	4.6	4.9	4.3	4.9
.....	6.0	4.8	9.0	5.4	4.8	4.6	5.9	5.3	4.7	4.4	4.3	5.0
.....	6.2	4.8	9.2	5.4	4.8	4.4	4.9	4.6	5.1	4.4	4.3	5.0
.....	6.4	4.8	8.6	5.2	4.8	4.4	4.6	4.4	5.2	4.9	4.3	5.0
.....	6.4	4.8	9.4	5.2	4.6	4.4	4.6	4.5	5.1	7.4	4.3	5.75
.....	5.8	4.8	14.8	5.2	4.6	4.1	4.6	4.5	4.9	7.0	4.3	18.65
.....	5.6	4.8	10.4	5.0	4.6	4.3	4.6	4.5	4.6	6.9	4.3	12.6
.....	5.4	4.8	8.8	5.0	4.4	6.3	5.9	4.4	4.6	6.1	4.3	10.5
.....	5.2	4.8	8.2	5.0	4.4	7.4	12.1	4.4	4.5	5.1	4.3	7.5
.....	5.4	4.8	8.0	4.8	4.2	7.5	7.9	16.0	4.4	4.7	4.3	6.9
.....	6.2	5.0	8.0	4.8	4.2	6.9	6.9	18.8	4.4	5.6	4.3	6.5
.....	5.8	5.6	7.6	4.8	4.2	6.5	5.1	12.5	4.3	5.7	4.3	5.9
.....	5.6	5.6	6.8	5.8	4.2	5.1	4.9	6.4	4.2	5.3	4.3	5.7
.....	5.6	.....	6.4	5.2	4.2	4.9	4.8	5.7	4.2	4.8	7.4	10.65
.....	5.6	.....	6.4	5.0	4.2	4.6	7.6	5.4	4.2	4.8	8.5	8.7
.....	5.6	.....	6.2	.....	4.2	.....	6.9	5.3	.....	4.7	.....	6.7

ozen at the gage Jan. 4-22 and Feb. 15-22, 1904.
an. 27 to Feb. 28, 1905, the river was frozen entirely across except for a narrow channel in the
age heights are to the surface of the water in a hole in the ice. Thickness of ice about 1

Daily gage height, in feet, of Monocacy River near Frederick, Md.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.[a]												
1	6.2	4.9	5.3	9.7	5.4	4.7	4.5	4.5	5.5	4.3	5.6	4.5
2	5.7	4.8	5.5	7.8	5.4	4.7	4.5	9.1	5.2	4.3	5.5	4.5
3	7.5	4.5	9.1	7.4	5.3	4.6	4.5	16.1	5.1	4.3	5.3	4.5
4	18.35	4.5	16.65	6.9	5.3	4.5	5.3	10.1	4.9	4.8	5.2	4.5
5	12.6	5.1	9.1	6.5	5.2	4.4	5.1	5.5	4.9	7.1	5.1	4.5
6	7.6	5.0	6.9	6.3	5.3	4.4	4.6	5.3	4.8	6.1	5.0	4.7
7	6.7	4.9	6.5	6.2	5.3	4.4	4.6	5.1	4.7	5.8	4.9	4.5
8	6.6	4.8	6.4	6.1	5.3	4.4	4.5	4.9	4.6	4.9	4.8	4.6
9	6.2	5.2	6.3	7.5	5.2	4.4	4.5	4.8	4.6	4.7	4.8	4.7
10	5.9	5.1	6.1	16.8	5.0	5.5	4.4	4.8	4.5	4.6	4.8	5.9
11	5.7	5.0	5.9	9.1	5.0	5.1	4.4	6.1	4.4	4.5	4.8	6.8
12	6.9	4.9	5.8	8.5	4.9	4.5	4.9	5.1	4.4	4.4	4.7	6.4
13	6.7	4.8	5.8	7.1	4.9	4.5	4.5	6.1	4.4	4.3	4.7	5.5
14	6.2	5.9	5.8	6.9	4.9	4.4	4.4	4.8	4.4	4.3	4.7	5.2
15	6.5	8.1	5.8	21.8	4.7	4.4	4.4	4.7	4.4	4.3	4.8	5.2
16	7.1	5.4	5.8	15.5	4.8	4.5	4.4	4.6	4.4	4.3	4.8	7.6
17	6.9	4.9	5.7	10.2	4.8	4.6	4.5	4.6	4.4	4.3	4.8	9.8
18	6.2	4.8	5.7	8.1	4.7	7.1	4.5	4.5	4.4	4.3	4.9	12.1
19	5.9	5.0	5.6	7.5	4.7	9.7	4.4	8.5	4.4	9.5	5.2	8.5
20	5.7	5.0	5.6	7.1	4.5	9.5	4.4	7.5	4.4	13.2	5.5	6.5
21	5.7	5.4	5.5	6.7	4.5	10.5	4.3	6.5	4.8	9.5	5.1	9.5
22	5.7	9.4	5.5	6.4	4.5	10.7	4.4	5.4	4.6	11.5	5.0	7.5
23	5.6	6.5	5.5	6.3	4.5	6.7	4.8	7.35	4.4	8.5	4.9	6.9
24	5.6	6.1	5.6	6.1	4.5	6.1	5.1	6.5	4.4	7.5	4.8	5.8
25	5.6	6.7	5.6	5.9	4.4	5.9	4.8	7.5	4.4	8.5	4.7	5.7
26	5.5	6.9	5.5	5.8	4.5	5.8	4.6	7.8	4.3	8.1	4.6	5.6
27	5.5	5.9	9.0	5.7	4.5	5.1	4.4	11.0	4.3	7.5	4.6	7.8
28	5.55	6.1	17.45	5.5	5.6	4.9	4.35	9.8	4.3	6.7	4.6	6.9
29	5.3	.....	12.5	5.4	5.1	4.8	4.5	7.5	4.3	6.2	4.5	5.8
30	5.2	.....	10.5	5.4	4.8	4.7	4.3	6.1	4.3	5.8	4.5	5.7
31	5.1	.....	9.6	.....	4.7	.....	4.3	5.8	.....	5.7	.....	8.4

[a] River frozen at the gage February 6–9, 1906.

Rating tables for Monocacy River near Frederick, Md.

AUGUST 4, 1896, TO DECEMBER 31, 1903.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.40	43	5.10	525	6.80	1,600	10.00	4,600
3.50	55	5.20	575	6.90	1,680	10.50	5,100
3.60	69	5.30	625	7.00	1,760	11.00	5,600
3.70	85	5.40	675	7.20	1,930	11.50	6,100
3.80	103	5.50	730	7.40	2,105	12.00	6,600
3.90	124	5.60	785	7.60	2,285	13.00	7,650
4.00	147	5.70	840	7.80	2,465	14.00	8,700
4.10	172	5.80	900	8.00	2,650	15.00	9,750
4.20	198	5.90	960	8.20	2,840	16.00	10,800
4.30	226	6.00	1,025	8.40	3,030	17.00	11,850
4.40	256	6.10	1,090	8.60	3,220	18.00	12,900
4.50	288	6.20	1,155	8.80	3,410	19.00	13,950
4.60	322	6.30	1,225	9.00	3,600	20.00	15,000
4.70	358	6.40	1,295	9.20	3,800	22.00	17,100
4.80	396	6.50	1,370	9.40	4,000	24.00	19,200
4.90	437	6.60	1,445	9.60	4,200	26.00	21,300
5.00	480	6.70	1,520	9.80	4,400		

[a] This table is strictly applicable only for open-channel conditions. It is based on discharge measurements made during 1896–1903. It is fairly well defined between gage heights 4.0 feet and 9.0 feet. Above gage height 12.0 feet the rating curve is a tangent, the difference being 105 per tenth

Rating tables for Monocacy River near Frederick, Md.—Continued.

JANUARY 1, 1904, TO DECEMBER 31, 1906.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet*	*Second feet.*
3.89	80	5.30	584	6.80	1,545	9.60	4,100
3.90	99	5.40	632	6.90	1,625	9.80	4,300
4.00	120	5.50	682	7.00	1,705	10.00	4,500
4.10	144	5.60	734	7.20	1,875	10.50	5,000
4.20	170	5.70	789	7.40	2,045	11.00	5,500
4.30	198	5.80	846	7.60	2,220	11.50	6,000
4.40	228	5.90	906	7.80	2,400	12.00	6,500
4.50	260	6.00	969	8.00	2,580	13.00	7,550
4.60	294	6.10	1,034	8.20	2,765	14.00	8,600
4.70	330	6.20	1,102	8.40	2,955	15.00	9,650
4.80	368	6.30	1,172	8.60	3,145	16.00	10,700
4.90	408	6.40	1,242	8.80	3,335	17.00	11,750
5.00	450	6.50	1,315	9.00	3,525	18.00	12,800
5.10	493	6.60	1,390	9.20	3,715	19.00	13,850
5.20	538	6.70	1,465	9.40	3,905	20.00	14,900

is table is strictly applicable only for open-channel conditions. It is based on discharge measure- made during 1904–1906. It is fairly well defined between gage heights 4.0 feet and 10.0 feet. Above eight 12.0 feet the rating curve is a tangent, the difference being 105 per tenth.

Estimated monthly discharge of Monocacy River near Frederick, Md.

[Drainage area, 660 square miles.a]

Month	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1896.								
ry							1.48	
ary							5.83	
							5.32	
							1.43	
							2.04	
							4.31	
							5.05	
t 4–31	256	69	125	.189	.197		b 1.44	
nber	480	69	115	.174	.194	6	2.94	2.75
er	396	103	144	.218	.251	19	1.31	1.06
ber	2,195	124	306	.464	.518	14	3.82	3.30
ber	396	124	187	.283	.326	41	.81	.48
The year							35.78	
1897.								
ry c	730	147	307	.465	.536	28	1.95	1.41
ary c	9,750	256	2,062	3.12	3.25	63	5.16	1.91
	4,400	575	1,384	2.10	2.42	84	2.88	.46
	3,900	322	907	1.37	1.53	53	2.86	1.33
	10,380	322	1,650	2.50	2.88	50	5.73	2.85
	2,195	198	492	.745	.831	27	3.10	2.27
	4,500	198	710	1.08	1.24	18	6.81	5.57
t d	11,010	172	968	1.47	1.70	46	3.70	2.00
nber d	812	114	191	.289	.322	15	2.12	1.80
er d	241	94	137	.208	.240	12	1.96	1.72
ber d	9,592	185	1,008	1.53	1.71	26	6.53	4.82
ber d	9,330	550	1,980	3.00	3.46	99	3.48	.02
The year	11,010	94	983	1.49	20.12	43	46.28	26.16

squares miles used for all years except 1904 and 1905, when 665 was used.
ecipitation for complete month August, 1896.
ver frozen at the gage January 25 to February 2, 1897; no correction made in estimates.
timates July 3 to December 31, 1897, liable to some error owing to uncertainty of wire length during eriod.

Estimated monthly discharge of Monocacy River near Frederick, Md.—Continued.

Month	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Means.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1898.								
January	7,020	416	2,099	3.18	3.67	95	3.86	0.19
February [a]	9,540	480	1,479	2.24	2.33	146	1.60	−.73
March	5,350	437	1,310	2.00	2.31	59	3.94	1.63
April	1,845	396	692	1.05	1.17	45	2.61	1.44
May	8,070	322	1,575	2.39	2.76	38	7.34	4.58
June	730	256	408	.618	.690	58	1.18	.49
July	675	124	223	.338	.390	12	3.14	2.75
August	7,020	147	926	1.40	1.61	24	6.75	5.14
September	198	103	128	.194	.216	15	1.46	1.24
October	6,150	103	693	1.05	1.21	20	5.97	4.76
November	6,068	256	1,132	1.72	1.92	43	4.42	2.50
December	12,850	480	1,943	2.94	3.39	81	4.17	.78
The year	12,850	103	1,051	1.59	21.67	47	46.44	24.77
1899.								
January [b]	9,592	480	1,971	2.99	3.45	109	3.16	−.29
February [b]	12,690	575	2,939	4.45	4.63	88	5.27	.64
March	12,000	1,370	3,428	5.19	5.98	115	5.19	−.79
April	7,230	396	1,179	1.79	2.00	115	1.74	−.26
May	2,375	322	680	1.03	1.19	25	4.74	3.55
June	5,700	198	750	1.15	1.28	41	3.09	1.81
July	288	124	196	.297	.342	11	3.17	2.83
August	525	103	208	.315	.363	9	4.02	3.66
September	1,025	85	309	.468	.522	10	5.16	4.64
October	480	103	133	.202	.233	9	2.64	2.41
November	2,015	172	401	.608	.678	30	2.23	1.55
December [b]	1,845	124	449	.680	.784	33	2.35	1.57
The year	12,690	85	1,054	1.59	21.44	50	42.78	21.34
1900.								
January [c]	4,800	288	1,030	1.56	1.80	81	2.22	.42
February [c]	15,840	525	2,641	4.00	4.16	73	5.69	1.53
March	8,175	675	2,188	3.32	3.83	111	3.44	−.39
April	1,295	358	576	.873	.974	68	1.43	.46
May	1,760	226	438	.664	.766	41	1.90	1.12
June	1,025	147	294	.445	.496	11	4.51	4.01
July	702	69	154	.233	.269	8	3.34	3.07
August	702	49	150	.227	.262	8	3.16	2.90
September [d]	147	55	82.1	.124	.138	6	2.31	2.17
October	172	85	102	.155	.179	7	2.59	2.41
November	3,800	85	454	.688	.768	21	3.64	2.87
December	6,705	124	520	.788	.908	30	3.02	2.11
The year	15,840	49	719	1.09	14.56	39	37.24	22.68
1901.								
January	2,285	147	438	.664	.766	27	2.82	2.06
February	525	226	329	.498	.519	60	.75	.23
March	15,530	256	2,167	3.28	3.78	69	5.48	1.70
April	12,900	675	2,742	4.15	4.63	72	6.47	1.84
May	6,100	396	1,521	2.30	2.65	49	5.36	2.71
June	2,650	288	839	1.27	1.42	33	4.26	2.84
July	730	172	316	.479	.552	11	5.04	4.49
August	1,845	147	445	.674	.777	13	6.22	5.44
September	1,520	172	296	.448	.500	13	3.77	3.27
October	575	172	268	.406	.468	34	1.38	.91
November	4,000	198	480	.727	.811	31	2.59	1.78
December	14,740	358	2,313	3.50	4.04	52	7.76	3.72
The year	15,530	147	1,013	1.53	20.92	40	51.90	30.98

[a] River frozen February 2–9, 1898; no correction made in estimates.
[b] River frozen at the gage January 2, February 9–21, and December 28–31, 1899; no correction made in the estimates.
[c] River frozen at the gage January 1–6 and February 1–4, 1900; no correction made in the estimates.
[d] Discharge interpolated September 29, 1900.

l monthly discharge of Monocacy River near Frederick, Md.—Continued.

	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Means.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
.....	12,950	437	1,924	2.92	3.37	93	3.61	0.24
.....	19,200	960	3,902	5.91	6.15	127	4.85	−1.30
.....	20,460	785	4,677	7.09	8.17	173	4.72	−3.45
.....	12,800	480	2,261	3.43	3.83	134	2.85	− .98
.....	575	226	339	.514	.593	55	1.08	.49
.....	1,845	147	323	.489	.546	12	4.44	3.89
.....	1,680	124	335	.508	.586	16	3.74	3.15
.....	575	60	143	.217	.250	15	1.67	1.42
.....	3,700	55	232	.352	.393	9	4.52	4.13
.....	8,385	172	1,157	1.75	2.02	28	7.20	5.18
.....	4,000	198	552	.836	.933	28	3.28	2.35
.....	11,960	730	3,981	6.03	6.95	110	6.33	− .62
...	20,460	55	1,652	2.50	33.79	70	48.29	14.50
.....	10,590	730	3,319	5.03	5.80	123	4.72	−1.08
.....	16,260	1,155	3,124	4.73	4.92	85	5.78	.86
.....	16,470	900	3,400	5.15	5.94	105	5.66	− .28
.....	16,680	840	3,532	5.35	5.97	105	5.69	− .28
.....	9,540	358	898	1.36	1.57	42	3.78	2.21
.....	16,260	437	1,806	2.74	3.06	35	8.68	5.62
.....	13,740	525	2,342	3.55	4.09	76	5.36	1.27
.....	6,705	288	1,063	1.61	1.86	28	6.74	4.88
.....	5,700	256	795	1.20	1.34	47	2.84	1.50
.....	1,930	226	477	.723	.834	26	3.16	2.33
.....	437	198	239	.362	.404	40	.99	.59
.....	6,652	172	540	.818	.943	42	2.26	1.32
.....	16,680	172	1,795	2.72	36.72	66	55.66	18.94
.....	14,800	260	1,069	1.61	1.86	54	3.46	1.60
.....	8,758	294	1,502	2.26	2.44	122	2.00	− .44
.....	11,960	538	1,812	2.72	3.14	97	3.23	.09
.....	2,400	294	729	1.10	1.23	56	2.21	.98
.....	780	198	375	.561	.647	22	2.98	2.33
.....	4,300	144	817	1.23	1.37	20	4.80	3.43
.....	2,765	120	586	.881	1.02	17	5.88	4.86
.....	7,130	80	436	.656	.756	18	4.32	3.56
.....	734	80	251	.377	.421	17	2.49	2.07
.....	960	80	209	.314	.362	17	2.12	1.76
.....	228	120	138	.208	.232	17	1.37	1.14
.....	3,905	120	549	826	.952	36	2.63	1.68
.....	14,800	80	706	1.06	14.43	38	37.49	23.06
.....	12,170	538	1,503	2.26	2.61	63	4.15	1.54
.....	734	368	409	.615	.640	35	1.83	1.19
.....	9,440	538	3,056	4.60	5.30	129	4.11	−1.19
.....	2,220	368	790	1.19	1.33	49	2.71	1.38
.....	450	170	279	.420	.484	26	1.84	1.36
.....	2,860	144	748	1.12	1.25	21	5.88	4.63
.....	6,605	200	1,296	1.95	2.25	27	8.32	6.07
.....	13,640	228	1,427	2.15	2.48	46	5.40	2.92
.....	2,130	170	546	.821	.916	29	3.17	2.25
.....	2,045	144	583	.877	1.01	23	4.39	3.38
.....	3,050	198	390	.586	.654	32	2.00	1.35
.....	13,480	468	2,124	3.19	.368	77	4.75	1.07
.....	13,640	144	1,096	1.65	22.60	47	48.55	25.95

rozen at the gage February 4-19, 1902, no correction made in the estimates.
rozen at the gage January 12-20, 1903; no correction made in the estimates.
rozen January 4-22 and February 15-22, 1904; no correction made in the estimates.
rozen January 27 to February 28, 1905; no correction made in the estimates.

Estimated monthly discharge of Monocacy River near Frederick, Md.—Continued.

Month.	Discharge in second-feet.			Run-off.			Precipitation.	
	Maximum.	Minimum.	Means.	Second-feet per square mile.	Depth in inches.	Per cent of precipitation.	In inches.	Loss in inches.
1906.								
January	13,170	493	1,657	2.51	2.89			
February[a]	3,905	260	824	1.25	1.30			
March	12,220	584	2,275	3.45	3.98			
April	16,700	632	2,877	4.36	4.86			
May	734	228	422	.639	.737			
June	5,200	228	1,037	1.57	1.75			
July	584	198	284	.430	.496			
August	10,800	260	1,776	2.70	3.11			
September	682	198	290	.439	.490			
October	7,700	198	1,494	2.25	2.59			
November	734	260	418	.633	.706			
December	6,605	260	1,428	2.17	2.50			
The year	16,700	198	1,232	1.87	25.41			

[a] River frozen at the gage February 6–9, 1906; no correction made in the estimates.

The following table gives the horsepower, 80 per cent efficiency per foot of fall, that may be developed at different rates of discharge, and shows the number of days on which the flow and the corresponding horsepower were respectively less than the amounts given in the columns for "discharge" and "horsepower."

Discharge and horsepower table for Monocacy River near Frederick, Md., from 1896 to 1906.

Discharge in second-feet.	Horsepower, 80 per cent efficiency, per foot fall.	Days of deficient flow.										
		1896.[a]	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	1906.
55	5	.....	.....	.....	.....	4	.....	.....	.....	.....	.....	.....
66	6	.....	.....	.....	.....	16	.....	10	.....	.....	.....	.....
88	8	16	.....	.....	4	63	.....	22	.....	21	.....	.....
110	10	32	6	22	29	89	.....	29	.....	27	.....	.....
132	12	74	19	37	56	119	.....	38	.....	78	.....	.....
154	14	98	45	48	75	142	1	48	.....	85	2	.....
176	16	114	56	58	100	163	25	72	4	123	17	.....
198	18	115	63	59	100	165	25	72	4	123	17	.....
220	20	128	86	68	118	174	74	94	15	129	36	18
275	25	136	115	99	140	196	131	115	56	152	78	82
330	30	142	130	116	163	213	155	147	78	187	106	99
385	35	142	149	123	169	224	165	152	94	216	151	138
440	40	145	171	138	187	244	204	170	128	240	169	154
495	45	147	192	157	206	254	216	176	130	259	195	175
550	50	147	199	169	213	265	229	185	138	269	205	184
660	60	148	222	206	231	275	243	207	154	285	220	202
770	70	149	243	234	243	289	264	217	173	297	237	226

[a] August 4 to December 31, 1896.

NOTE.—The minimum flow during the period covered by the above table was 49 second-feet, giving 4.5 horsepower per foot of fall for four consecutive days during August, 1900.

POTOMAC RIVER AT GREAT FALLS, MD., AND AT CHAIN BRIDGE, D. C.

Estimates of the flow of Potomac River at Chain Bridge and at eat Falls are not considered sufficiently accurate for republication ing to poor conditions at the Chain Bridge section and the effect the flow of the river of a daily range of tide of about 3 feet. Esti- ates at Great Falls, as previously published, were based on the dis- arge at Chain Bridge, and hence are subject to the same errors. e flood discharges as determined at these two stations are probably curate enough for all practical purposes, but for medium and low ges the estimates are considered too high and likely to be very sleading if used.

ROCK CREEK AT LYON'S MILL AND ZOOLOGICAL PARK, D. C.

Rock Creek rises south of Laytonsville, in the central part of Mont- mery County, Md., and flows southward into Potomac River at ashington, D. C. The total drainage area at the mouth is 86 square les.

A study of the discharge of Rock Creek was begun in July, 1892, the request of the Commissioners of the District of Columbia. gust 18, 1892, a self-registering gage was placed at Lyon's Mill ad Bridge, at the east corner of Oak Hill Cemetery, Georgetown, C. C. Babb. The gage-height record was continued until Novem- 30, 1894.

January 18, 1897, a new station was established by E. G. Paul at Park Bridge, near the eastern entrance of the National Zoological rk, Washington, D. C. The staff gage was above and within the uence of a dam. Measurements were made at various cross tions. The bridge was rebuilt and the gage destroyed in November, 0.

The estimated discharge of Rock Creek at Lyon's mill, which is olished below for the first time, is probably within 5 per cent of true discharge above gage height, −0.3 foot. Below gage height, .3 foot, the probable error may vary from 5 to 15 per cent. The ct of ice conditions is not known.

No estimates are possible for Rock Creek at Zoological Park, owing the insufficient range of stage at which measurements were made.

Discharge measurements of Rock Creek, at Lyon's mill, Washington, D. C.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1892.	*Feet.*	*Second-feet.*	1893.	*Feet.*	*Second-feet.*
y 28	0.00	89	April 11	− .12	58
gust 2	− .30	49	May 4	4.14	959
gust 3	− .30	48	1894.		
gust 5	.19	102	May 7	1.10	223

Discharge measurements of Rock Creek referred to Zoological Park Bridge gage, District of Columbia.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1897.	*Feet.*	*Second-feet.*	1900.	*Feet.*	*Second-feet.*
August 18[a]	2.90	26	April 24[d]	2.75	77
November 21[b]	3.00	37	1902.		
1898.			February 27[d]		1,820
January 28[c]	3.23	89			
May 18[c]	3.20	95			

[a] Measured at Woodley Bridge.
[b] Measured at Klingle Ford.
[c] Measured at Lyon's mill.
[d] Measured at Rustic Bridge.

Daily gage height, in feet, of Rock Creek at Lyon's mill, Washington, D. C.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1892.						1892.					
1		−0.65	−0.68	−0.68	−0.40	17		− .65	− .68	− .42	− .30
2		− .69	− .70	− .70	− .52	18	−0.58	− .72	− .65	− .55	− .35
3		− .66	− .72	− .64	− .55	19	− .60	− .72	− .58	+ .22	− .35
4		− .62	− .72	− .61	− .56	20	− .60	− .72	− .68	− .33	− .35
5		− .71	− .72	− .68	− .54						
						21	− .63	− .70	− .63	− .32	− .40
6		− .68	− .71	− .66	− .53	22	− .63	− .55	− .62	− .32	− .35
7		− .67	− .70	− .65	− .53	23	− .62	+ .50	− .62	− .60	− .40
8		− .72	− .68	− .65	− .50	24	− .62	.00	− .62	− .59	− .35
9		− .71	− .58	− .30	− .52	25	− .58	− .58	− .70	− .61	− .35
10		− .71	− .65	− .15	− .53						
						26	− .61	− .60	− .65	− .61	− .35
11		− .72	− .70	− .25	− .61	27	− .66	− .62	− .65	− .61	− .35
12		− .72	− .70	− .51	− 61	28	− .61	− .66	− .66	− .55	− .35
13		− .72	− .71	− .45	− .60	29	− .68	− .65	− .65	− .51	− .35
14		− .10	− .72	− .54	+ .30	30	− .68	− .68	− .66	− .46	− .35
15		.00	− .70	− .44	+ .50	31	− .63		− .68		− .35
16		− .58	− .62	− .44	− .20						

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1893.												
1	+1.00	.21	+1.38	− 0.27	+0.10	−0.30	− 0.42	−0.75	−0.70	−0.87	−0.65	−0.30
2	+1.22	.12	+ .54	.30	− .10	− .22	− .47	− .76	− .66	− .88	− .65	− .35
3	− .17	.15	+ .22	.35	− .20	− .13	− .50	− .80	− .80	− .90	− .65	+ .30
4	− .20	+ .03	+ .18	.30	+4.20	− .17	+1.00	− .79	− .82	− .80	− .62	+ .30
5	− .29	.31	.00	.30	+ .75	+ .20	+ .16	− .76	− .91	− .70	− .64	− .30
6	− .20	.32	− .01	− .32	+ .52	− .25	− .52	− .79	− .92	− .72	− .68	− .35
7	− .41	− .22	.00	.32	+ .20	− .35	− .55	− .80	− .90	− .75	− .66	− .35
8	− .59	.00	− .02	− .30	+ .05	− .25	− .60	− .85	− .93	− .80	− .90	− .35
9	− .40	.44	+ .40	.30	.00	− .46	.00	− .85	−1.00	− .81	+1.65	− .35
10	− .28	− .02	+ .50	.30	+ .10	.45	− .48	− .86	− .99	− .82	+ .05	− .35
11	− .20	+ .25	+ .08	− .20	− .12	.50	− .55	− .88	− .97	− .90	− .37	− .35
12	− .41	+ .20	+ .22	.28	− .12	− .52	− .60	− .90	− .66	− .90	− .38	− .35
13	− .41	+2.00	+ .34	− .08	− .15	− .45	− .60	− .90	− .74	− .90	− .45	− .35
14	− .35	+1.30	.00	− .18	.00	− .50	− .61	− .95	+ .10	+2.20	− .50	− .35
15	− .35	+ .95	.00	− .09	− .15	− .51	+2.20	−1.00	− .56	− .20	.00	− .35
16	− .10	+ .35	− .10	− .09	− .15	− .51	− .18	−1.00	− .50	− .50	− .27	− .35
17	− .32	+ .12	− .10	− .36	+ .40	− .52	− .40	−1.00	− .60	− .75	− .34	− .35
18	− .32	.00	− .06	− .22	.00	− .51	− .34	− .90	− .62	− .62	− .40	− .35
19	− .32	− .04	− .06	− .26	− .05	− .51	− .45	−1.00	− .68	− .70	− .45	− .35
20	− .33	− .12	− .10	− .27	− .10	− .51	− .53	−1.05	− .85	− .75	− .50	− .35
21	− .38	− .32	− .10	+ .40	− .10	− .54	− .57	− .96	− .90	− .76	− .40	− .35
22	− .38	− .09	− .10	− .00	− .05	− .55	− .61	−1.08	− .80	− .75	+ .25	− .35
23	− .38	− .46	− .11	+ .18	− .07	− .55	− .65	− .88	− .90	+ .30	− .30	− .35
24	− .36	− .12	− .06	− .05	− .12	+ .47	− .67	−1.00	− .90	− .40	− .34	− .35
25	− .36	− .09	− .06	− .22	− .15	− .32	− .69	−1.05	− .92	− .54	− .35	− .35
26	− .21	+ .15	− .05	− .21	− .20	− .37	− .70	−1.09	− .94	− .61	− .36	− .35
27	+ .15	+ .10	− .08	+ .20	− .20	− .35	− .65	− .92	− .85	− .61	− .35	− .35
28	+ .23	.00	− .08	+ .20	− .12	− .39	− .71	− .94	− .85	− .60	+ .85	− .35
29	+ .15	.....	− .08	.00	− .12	− .40	− .71	+1.36	− .80	− .60	.00	− .35
30	+ .15	.....	− .08	+ .10	− .15	− .45	− .72	− .50	− .80	− .60	− .15	− .35
31	− .15	.....	− .20	.....	− .02	.....	− .74	− .80	.....	− .60	.....	− .35

ily gage height, in feet, of Rock Creek at Lyon's mill, Washington, D. C.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1894.												
	−0.22	−0.14	−0.20	−0.24	−0.45	−0.40				−0.60	−0.10	
2	− .32	− .14	− .12	− .24	− .41	− .41			−0.85	− .60	− .50	
3	− .34	− .28	+1.00	− .26	− .39	− .44			− .80	− .50	− .10	
4	− .31	− .30	+ .62	− .25	− .34	− .50			− .80	− .60	− .00	
5	− .33	− .36	+ .12	− .30	− .20	− .51			− .82	− .40	− .45	
6	− .30	− .30	+ .04	− .36	+ .21	− .51			− .85	− .50	− .50	
7	− .31	− .30	+ .05	− .36	+ .60	− .52			− .85	− .60	− .55	
8	− .33	− .31	− .05	− .28	+ .03	− .55			− .80	− .70	− .60	
9	− .31	− .32	− .12	− .28	− .20	− .64	− .85		− .70	− .80	− .30	
10	− .33	− .30	− .21	− .18	− .26	− .64	− .92		− .60	− .50	− 45	
11	− .33	− .27	− .20	+1.18	− .28	− .66	− .92		− .55	− .20	− .50	
12	− .28	− .28	− .20	+ .69	− .28	− .68			− .65	− .60	− .60	
13	− .31	− .32	− .22	+ .65	− .29	− .69			− .70	− .70	− .60	
14	− .24	− .34	− .25	+ .21	− .31	− .71			− .65	− .70	− .65	
15	− .24	− .20	− .24	.00	− .31	− .73			− .65	− .70	− .70	
16	− .24	.00	− .24	− .07	− .32				− .65	− .70	− .70	
17	− .25	+ .12	− .22	− .11	− .48				− .65	− .70	− .70	
18	− .26	+ .42	− .23	− .15	− .32				− .70	− .70	− .70	
19	− .29	+ .65	− .23	− .18	− .28				− .70	− .70	− .65	
20	− .30	.00	− .23	− .19	+ .65			−1.10	− .70	− .75	− .70	
	− .26	− .12	− .21	− .22	+ .23			−1.10	− .70	− .80	− .70	
	− .24	− .20	− .20	− .25	− .10			−1.10	− .70	− .80	− .70	
	− .20	− .20	− .18	− .30	− .27			−1.00		− .75	− .70	
	− .21	− .20	− .20	− .33	− .30			−1.10		− .75	− .70	
	− .20	− .20	− .20	− .37	− .33			−1.20		− .75	− .70	
	− .20	− .20	− .17	− .31	− .30			−1.25		− .75	− .70	
	− .20	− 26	− .20	− .39	− .30			− .90		− .75	− .65	
	− .21	− .20	− .20	− .34	− .32			−1.20		− .75	− .70	
	− .16		− .22	− .40	− .36			−1.10		− .72	− .70	
	+1.00		− .21	− .42	− .36					− .70	− .70	
	.00		− .22		− .36					− .70		

Daily gage height, in feet, of Rock Creek at Zoological Park, D. C.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897.												
1		2.9	2.35	2.3	2.3	2.3	3.1	3.05	2.85	2.8	3.1	3.05
2		3.5	2.35	2.25	2.4	2.5	3.1	3.0	2.85	2.85	3.5	3.05
3		4.15	2.35	2.25	2.45	2.65	3.1	3.0	2.85	2.85	3.3	3.05
4		3.45	2.4	2.25	2.55	2.95	3.05	2.95	2.85	2.85	3.1	3.25
5		3.15	2.35	2.5	2.5	2.15	3.05	2.95	2.85	2.85	3.05	3.9
6		3.25	2.35	2.65	2.35	3.1	3.05	3.0	2.85	2.85	3.0	3.35
7		4.25	2.4	2.45	2.3	3.25	3.05	2.95	2.8	2.85	2.95	3.2
8		2.7	2.35	2.4	2.2	3.4	3.6	2.95	2.8	2.85	3.0	3.15
9		2.45	2.35	3.15	2.2	3.45	3.15	2.95	2.8	2.85	3.2	3.1
10		2.4	2.35	2.9	2.15	3.4	3.1	2.95	2.8	2.85	3.35	3.1
11		2.3	2.3	2.6	2.2	3.4	3.1	3.0	2.8	2.85	3.1	3.1
12		2.45	2.3	2.5	2.5	3.35	3.25	3.0	2.8	3.15	3.05	3.1
13		2.6	2.35	2.45	3.7	3.35	3.3	2.95	2.8	2.85	3.05	3.1
14		2.6	2.45	2.45	2.65	3.35	3.3	2.9	2.8	2.85	3.0	3.25
15		2.7	2.6	2.4	2.95	3.35	3.1	2.9	2.8	2.85	3.05	4.3
16		2.45	2.4	2.45	2.6	3.35	3.0	2.95	2.8	2.85	3.1	3.35
17		2.35	2.35	2.45	2.5	3.35	3.1	3.0	2.8	2.85	3.05	3.2
18	3.0	2.3	2.95	2.4	2.4	3.35	3.1	2.9	2.9	2.9	3.05	3.15
19	2.95	2.3	2.85	2.35	2.4	3.2	3.45	2.9	2.85	2.9	3.05	3.1
20	2.9	2.25	3.05	2.3	2.35	3.3	3.25	2.9	2.8	3.0	3.05	3.1
21	3.15	2.4	2.9	2.3	2.3	3.25	3.25	2.9	2.8	3.0	3.0	3.15
22	3.3	3.75	2.65	2.3	2.3	3.15	4.0	2.9	2.8	2.95	3.0	3.2
23	3.35	4.1	2.55	2.3	2.25	3.15	3.4	2.9	2.9	2.95	3.05	3.2
24	3.05	2.9	2.5	2.3	2.6	3.15	3.1	2.95	3.2	3.0	3.05	3.3
25	2.85	2.6	2.55	2.3	3.45	3.25	3.05	2.9	2.9	3.1	3.0	3.05
26	3.0	2.5	2.4	2.25	2.55	3.15	3.0	2.9	2.8	3.1	3.05	3.1
27	2.9	2.45	2.4	2.25	2.4	3.1	3.45	2.9	2.8	3.0	3.95	3.1
28	2.9	2.45	2.35	2.2	2.35	3.1	4.3	2.85	2.8	2.95	3.3	3.05
29	2.95		2.3	2.25	2.3	3.1	3.1	2.85	2.8	2.9	3.15	3.0
30	2.9		2.3	2.25	2.3	3.1	3.1	2.85	2.8	2.9	3.1	3.1
31	2.9		2.8		2.25		3.1	2.85		2.9		3.1

Daily gage height, in feet, of Rock Creek at Zoological Park, D. C.—Continued.

Day	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1888.												
1	3.1	3.15	3.1	3.3	3.5	2.95	2.85	2.8	2.45	2.3	2.8	2.8
2	2.95	3.15	3.1	3.2	3.5	2.95	2.8	2.8	2.4	2.35	2.65	2.4
3	3.1	3.1	3.1	3.2	3.5	2.95	2.8	2.8	2.4	2.35	2.6	2.4
4	3.05	3.1	3.15	3.1	3.0	2.9	2.8	2.8	2.4	2.4	2.6	3.15
5	3.05	3.05	3.15	3.2	3.5	2.9	2.85	3.9	2.4	2.4	2.6	4.6
6	3.0	3.05	3.1	3.15	3.2	2.9	2.85	2.85	2.4	2.4	2.65	3.15
7	3.05	3.05	3.1	3.1	3.95	2.9	2.8	2.8	2.4	2.4	2.65	3.0
8	3.05	3.05	3.1	3.1	3.4	2.9	2.8	2.8	2.35	2.35	2.6	2.9
9	3.05	3.1	3.05	3.1	3.3	2.9	2.8	2.9	2.35	2.35	2.6	2.85
10	3.9	3.1	3.05	3.1	3.0	2.9	2.8	3.45	2.35	2.35	2.65	2.85
11	3.35	3.1	3.05	3.05	3.0	2.9	2.8	3.7	2.35	2.35	3.4	2.75
12	3.2	3.1	3.05	3.15	3.15	2.9	2.75	4.0	2.3	2.4	3.35	2.8
13	3.3	3.1	3.05	3.15	3.15	2.9	2.75	4.15	2.3	2.4	2.7	2.85
14	3.2	3.05	3.05	3.15	3.15	2.9	2.75	3.95	2.3	2.45	2.65	2.8
15	3.4	3.05	3.05	3.15	3.1	2.9	2.8	2.75	2.3	2.4	2.65	2.8
16	4.1	3.05	3.05	3.1	3.1	2.85	2.8	2.8	2.3	2.45	2.65	2.8
17	3.3	3.0	3.25	3.1	3.9	2.85	2.75	2.55	2.3	2.45	2.8	2.75
18	3.25	3.05	3.2	3.1	3.1	2.85	2.75	2.55	2.3	2.4	3.25	2.75
19	3.15	3.25	3.1	3.6	3.1	2.9	2.95	3.15	2.3	2.9	4.05	2.8
20	3.2	3.5	3.1	3.2	3.1	2.85	2.9	2.75	2.3	2.75	3.1	2.35
21	3.35	3.75	3.05	3.3	3.3	2.85	2.9	2.75	2.25	2.6	2.85	2.35
22	3.2	3.4	3.05	3.3	3.5	2.85	2.8	2.7	2.3	2.75	2.8	2.9
23	3.25	3.25	3.05	3.3	3.5	2.8	2.75	2.6	2.45	2.9	2.8	4.6
24	3.3	3.2	3.1	3.1	3.5	2.8	2.75	2.6	2.6	2.7	2.8	3.05
25	3.15	3.15	3.5	3.15	3.65	2.8	2.75	2.55	2.35	2.65	2.75	2.9
26	3.65	3.1	3.2	3.1	3.5	2.8	2.75	2.55	2.35	2.55	2.8	2.8
27	3.4	3.1	3.1	3.65	3.5	2.8	3.1	2.5	2.3	2.6	2.75	2.8
28	3.25	3.1	3.1	3.1	3.0	3.1	3.1	2.5	2.3	2.6	2.75	2.8
29	3.15	.....	3.15	3.1	3.0	2.95	3.0	2.5	2.3	2.6	2.8	2.7
30	3.15	.....	3.95	3.1	2.95	2.9	2.8	2.5	2.3	2.85	2.85	2.75
31	3.15	.....	3.45	.....	2.95	.....	2.8	2.45	.....	2.95	.....	2.8
1889.												
1	3.05	2.78	3.3	3.0	2.75	2.88	2.4	2.35	2.4	2.58	3.65	2.85
2	2.75	2.88	3.23	2.93	2.7	2.68	2.4	2.35	2.4	2.5	2.5	2.86
3	2.88	2.88	3.13	2.9	2.73	2.63	2.35	3.9	2.4	2.5	2.8	2.81
4	2.9	2.95	3.1	2.9	2.7	2.6	2.35	3.2	2.4	2.5	3.1	2.75
5	3.33	3.13	4.5	2.9	2.7	2.55	2.6	2.65	2.38	2.5	2.8	2.75
6	3.05	3.0	3.4	2.9	2.7	2.55	2.58	2.9	2.3	2.75	2.7	2.5
7	4.25	3.0	3.18	2.95	2.75	2.55	2.7	2.55	2.3	2.7	2.63	2.5
8	3.23	2.93	3.1	3.8	2.75	2.53	2.5	2.5	2.3	2.58	2.6	2.5
9	3.05	2.93	3.1	3.08	3.23	2.5	2.78	2.48	2.3	2.6	2.6	2.5
10	3.0	2.93	3.08	3.0	2.83	3.63	2.48	2.53	2.3	2.58	2.6	2.5
11	3.0	2.78	3.23	2.9	2.83	2.58	2.43	2.5	2.4	2.55	2.6	2.5
12	3.1	2.78	3.18	2.9	2.98	2.73	2.4	2.48	2.43	2.5	2.58	2.5
13	2.9	2.78	3.13	2.9	2.78	2.65	2.5	2.45	2.3	2.5	2.55	2.5
14	3.0	2.78	3.0	2.9	2.73	2.63	2.7	2.75	2.3	2.5	2.55	2.5
15	3.0	2.95	3.1	2.85	2.7	2.55	2.45	2.5	2.3	2.5	2.55	2.5
16	3.0	2.95	3.3	3.05	2.68	2.5	2.45	2.7	2.25	2.5	2.55	2.5
17	3.1	4.0	3.0	3.0	2.73	2.5	2.9	2.5	2.25	2.5	2.55	2.5
18	3.08	4.25	3.05	2.9	3.25	2.5	2.58	2.45	2.3	2.5	2.55	2.5
19	2.98	4.43	3.9	2.85	2.95	2.5	2.45	2.43	2.43	2.5	2.58	2.5
20	2.93	4.05	3.33	2.85	2.78	2.5	2.4	2.4	3.0	2.5	2.55	2.5
21	3.13	3.88	3.1	2.8	2.7	2.48	2.4	2.4	2.63	2.5	2.55	2.5
22	2.85	4.18	3.18	2.8	2.7	2.45	2.4	2.73	2.55	2.45	2.55	2.5
23	2.85	4.1	3.18	2.8	2.68	2.45	2.4	2.45	2.4	2.45	2.6	2.5
24	2.85	3.5	3.03	2.8	2.65	2.45	2.4	2.35	2.35	2.48	2.63	2.5
25	3.08	3.2	3.0	2.8	2.6	2.48	2.4	2.3	2.65	2.45	2.6	2.5
26	3.08	3.15	3.0	2.8	2.6	2.53	2.5	2.3	5.25	2.45	2.6	2.5
27	3.0	3.7	3.0	2.83	2.6	2.5	2.5	2.55	3.75	2.5	2.55	2.5
28	2.88	3.33	3.23	2.78	2.6	2.48	2.4	2.75	2.85	2.5	2.55	2.5
29	2.85	.....	3.45	2.75	2.65	2.45	2.4	2.48	2.6	2.5	2.55	2.5
30	2.83	.....	3.15	2.75	2.6	2.43	2.4	2.4	2.6	2.5	2.55	2.5
31	2.85	.....	3.03	.....	2.6	.....	2.38	2.4	.....	2.63	.....	2.5

Daily gage height, in feet, of Rock Creek at Zoological Park, D. C.—Continued.

Day	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1900.												
	2.45	2.43	3.3	2.75	2.6	2.45	2.35	2.35	2.15	2.4	2.1	
	2.43	2.43	3.25	2.7	2.6	2.73	2.35	2.28	2.13	2.3	2.15	
	2.43	2.38	2.88	2.7	2.6	2.6	2.35	2.3	2.1	2.2	2.15	
	2.4	2.4	2.78	2.7	2.6	2.55	2.4	2.28	2.1	2.2	2.28	
	2.38	3.03	2.75	2.68	2.6	2.5	2.38	2.25	2.1	2.2	2.35	
	2.4	2.6	2.8	2.65	2.55	2.45	2.38	2.25	2.1	2.2	2.28	
	2.4	2.53	2.85	2.65	2.55	2.45	2.38	2.23	2.1	2.15	2.25	
	2.4	2.83	2.73	2.65	2.55	2.58	2.35	2.2	2.1	2.25	2.4	
	2.4	2.95	2.7	2.63	2.6	2.45	2.33	2.2	2.1	2.25	2.48	
	2.4	2.68	2.68	2.6	2.63	2.45	2.3	2.2	2.1	2.2	2.43	
	2.43	2.6	2.65	2.6	2.58	2.4	2.3	2.2	2.1	2.2		
	3.6	2.68	2.7	2.8	2.55	2.35	2.3	2.15	2.1	2.2		
	3.03	3.88	2.7	2.75	2.53	2.45	2.3	2.18	2.1	2.23		
	2.88	3.0	2.7	2.68	2.5	2.48	2.3	2.15	2.1	2.35		
	2.58	2.8	2.68	2.65	2.5	2.68	2.3	2.15	2.13	2.35		
	2.53	2.75	2.7	2.65	2.5	2.65	2.3	2.15	2.65	2.3		
	2.8	2.7	2.78	2.7	2.5	4.3	2.3	2.15	2.4	2.25		
	2.8	2.7	2.8	2.7	2.5	3.45	2.3	2.15	2.2	2.2		
	2.83	2.7	2.8	3.1	2.9	2.78	2.3	2.1	2.17	2.2		
	3.08	2.78	3.75	2.8	2.73	2.7	2.4	2.1	2.15	2.2		
	3.13	2.73	3.18	2.73	2.55	2.58	2.4	2.18	2.15	2.2		
	2.88	5.2	2.85	2.8	2.5	2.55	2.48	2.28	2.15	2.2		
	2.8	3.35	2.8	2.8	2.5	2.5	2.4	2.23	2.15	2.2		
	2.75	2.9	2.78	2.75	2.45	2.5	2.73	2.25	2.15	2.25		
	2.68	2.9	2.73	2.7	2.5	2.5	2.48	2.48	2.15	2.23		
	2.6	3.08	2.75	2.7	2.5	2.48	2.35	2.28	2.15	2.18		
	2.58	3.05	2.8	2.7	2.45	2.48	2.38	2.2	2.15	2.15		
	2.68	2.78	2.8	2.65	2.45	2.43	2.3	2.2	2.45	2.15		
	2.48		2.8	2.6	2.45	2.35	2.3	2.2	2.4	2.1		
	2.48		2.8	2.6	2.45	2.35	2.3	2.2	2.6	2.1		
	2.55		2.8		2.4		2.5	2.15		2.1		

Rating table for Rock Creek at Lyon's mill, Washington, D. C., from August 18, 1892, to November 30, 1894.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
−1.30	5	−0.10	68	1.10	220	2.60	533
−1.20	6	.00	78	1.20	235	2.80	583
−1.10	8	.10	89	1.30	251	3.00	635
−1.00	10	.20	100	1.40	268	3.20	689
−.90	13	.30	112	1.50	286	3.40	744
−.80	17	.40	124	1.60	305	3.60	800
−.70	22	.50	137	1.70	325	3.80	858
−.60	28	.60	150	1.80	346	4.00	918
−.50	34	.70	163	1.90	368	4.20	980
−.40	41	.80	177	2.00	390		
−.30	49	.90	191	2.20	436		
−.20	58	1.00	205	2.40	484		

[a] This table is strictly applicable only for open-channel conditions. It is based on seven discharge measurements made during 1892–1894. It is well defined between gage heights −0.3 foot and 4.2 feet.

Estimated monthly discharge of Rock Creek at Lyon's mill, Washington, D. C.

[Drainage area, 85 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1892.					
August 18–31	29	23	26.4	0.311	0.162
September	137	21	32.8	.386	.431
October	29	21	23.7	.279	.322
November	102	22	35.4	.416	.464
December	137	27	44.5	.524	.604
1893.					
January	238	29	65.7	.773	.891
February	390	37	94.0	1.11	1.16
March	265	58	88.5	1.04	1.20
April	124	44	65.9	.775	.865
May	980	58	107	1.26	1.45
June	133	31	46.0	.541	.604
July	436	20	53.0	.624	.719
August	261	8	22.0	.259	.299
September	89	10	19.8	.233	.260
October	436	13	39.3	.462	.533
November	315	23	56.5	.665	.742
December	198	32	58.6	.689	.794
The year	980	8	59.7	.703	9.52
1894.					
January	205	46	56.0	.659	.760
February	156	44	63.0	.741	.772
March	205	54	68.6	.807	.930
April	232	40	67.8	.798	.890
May	150	35	59.6	.701	.808
June 1–15	41	20	29.8	.351	.196
August 20–29	13	6	8.1	.095	.035
September 2–22	31	15	21.4	.252	.197
October	58	17	24.9	.293	.338
November	78	22	31.3	.368	.411

MISCELLANEOUS MEASUREMENTS IN POTOMAC RIVER DRAINAGE BASIN BELOW SHENANDOAH RIVER.

William Rich Hutton, of New York, states that in the summer of 1856 he made a careful examination of the flow of Potomac River a short distance below Great Falls, using loaded poles reaching as near as possible to the bottom and placed at 5-foot intervals across the width of the river. The water was then at the lowest stage known to persons who had observed the river for many years. The discharge was 1,063 second-feet. Mr. Hutton was of the opinion that the river was as low in 1862, but no measurements were made in that year.

In 1839 a civil engineer, M. C. Ewing, assistant to Major Turnbull, United States topographic engineer, during the construction of the Alexandria Aqueduct above Georgetown, reported the discharge below Little Falls to be 1,904 second-feet. Thomas L. Patterson, of Cumberland, is reported to have found the discharge of North Branch of the Potomac at that point in the low water of 1838 to be 24 second-feet, and at Patterson Creek, about 12 miles below, 48 second-feet. Figures of discharge of Potomac River are given in the statement regarding the extension of the Chesapeake and Ohio Canal in House Ex. Doc. No. 208, Forty-third Congress, first session; also *in House* Ex. Doc. No. 137, Forty-fourth Congress, first session.

The following miscellaneous discharge measurements were made in the Potomac River drainage basin by hydrographers in the United States Geological Survey. Measurements in the fall of 1897 were made in connection with a study of the sources of pollution in the Potomac drainage basin. They were made at a time when the flow throughout the basin was considered generally lower than usual, although a few measurements were affected by local rains which preceded them.

Miscellaneous discharge measurements in Potomac River basin below Shenandoah River.

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
1897.			*Feet.*	*Square feet.*	*Feet per second.*	*Second-feet.*
October 14	Carroll Creek (tributary to Monocacy River).	Zentz's mill race, Frederick, Md.	7	4	1.40	5.6
Do.	....do....	At Frederick, Md.	11	6	1.00	6
Do.	Goose Creek	¼ mile above mouth, near Edwards Ferry, Md.	34	38	.50	19
Do.	Catoctin Creek, in Maryland.	Above Baltimore and Ohio R. R. bridge near Catoctin station, Md.	21	9	2.22	20
Do.	Broad Run	Near Edwards Ferry, Md.				1
October 15	Seneca Creek	In Seneca mill race, Seneca, Md.	11	20	1.25	25
Do.	Catoctin Creek in West Virginia.	½ mile above mouth and 1 mile above Point of Rocks, Md.	16	6	1.17	7
Do.	South Tuscarora Creek.	Near Baltimore and Ohio R. R. bridge near Licksville, Md.	5	2.5	1.24	3.1
Do.	Monocacy River	Between Baltimore and Ohio R. R. bridge and canal aqueduct near Dickerson, Md.	203	184	1.19	[a]219

[a] Gage height on Monocacy River at Frederick, Md., 4.4 feet.

FLOODS NEAR WASHINGTON, D. C.

FLOOD OF FEBRUARY, 1881.[a]

February 12 and 13, 1881, there occurred in the vicinity of Washington the greatest flood, with the exception of that of June 2, 1889, hereinafter described, of which there is any record.

This flood was caused by the gorging effect of an ice jam, and the discharge did not equal that of the freshet of 1877 or 1889, but the amount of damage inflicted on shipping, wharf property, and private property was far greater. The low portion of the city along the Mall and extending across Pennsylvania avenue was flooded, and a large amount of damage was caused by the flooding of cellars and first floors. The area of the flooded district was about 254 acres.

The winter had been unusually severe in the long continuance and intensity of its period of cold, during which 23.2 inches of snow had fallen and unusually thick ice had formed over the river. A rise of only a few feet in the river from rains and melted snow caused a

[a] Chiefly from Ann. Rept. Chief of Engineers, U. S. Army, 1881, pt. 1, pp. 940-942.

breaking up of this ice, which gorged and so obstructed the waterway that although the freshet above Georgetown did not attain the height of 1877 by 3 feet, the water rose to a height of 12.25 feet above low water at Long Bridge, or 3.19 feet higher than the freshet of 1877.

The ice broke at Georgetown about 1 a. m. on Saturday, February 12, 1881, the stage of the river being then 2 to 3 feet above high tide, but rapidly rising as the ice passed down and added to the gorge below, until the highest water was reached at 7 p. m., when it was about 0.8 foot higher than the flood of 1877.

At Georgetown comparatively little damage was done, owing chiefly to the precaution taken to secure shipping and movable property on the wharves. Along the Washington wharves the ice began to break about 2 a. m., the water being 4 to 5 feet above high tide, and moved off rapidly with the current, the channel at times being nearly clear of ice.

The gorge did not at first form at Long Bridge, so far at least as concerned the Washington Channel, as is proved from the fact that between 3 and 4 a. m. on Saturday, February 12, a long boat and several scows were swept away from the Seventeenth street wharf and carried through the Washington draw, and the long boat was found later in the day lodged in the gorge below Arsenal Point, the scows having been carried still farther down the river.

The complete gorge was formed below Arsenal Point, commencing about 7.30 a. m., and the successive additions of floating ice soon caused it to extend to Long Bridge.

Whether a gorge was complete across Georgetown Channel at this point before the lower gorge extended to the bridge was not determined, but subsequently the gorge became complete for the whole length of the bridge. It is probable, however, from the fact that large quantities of ice came across the flats above Long Bridge and passed through the Washington Channel, that a gorge independent of that below was formed across Georgetown Channel at Long Bridge at or about the time of its formation below.

By 9 a. m. the entire waterway of Long Bridge was choked. An occasional movement of short duration served only to jam the ice more closely and raise it higher, until the water passed over the causeway and 2.2 feet above it. The pressure on the bridge became greater than it could withstand, and about 8.30 p. m. three spans of the north end gave way and were swung around on the flats below. This movement, together with a break in the railroad embankment between the river and Fort Runyon (which is one-third of a mile from the Virginia end of Long Bridge, on the railroad to Alexandria) 1,006 feet in length, so far relieved the pressure that no further damage was done to the bridge.

GREAT FALLS OF THE POTOMAC.

By Sunday morning the water, which had been 2½ feet higher on ıe Washington wharves than in the freshet of 1877, was off the harves, but large piles of ice remained upon them, and many hich escaped serious injury from lateral pressure while the ice was ınning were crushed when the water, by its subsidence, withdrew s buoyant support.

The following are the heights above low water of the freshets of 377 and 1881 at the several points named:

Height of Potomac River above low water in floods of 1877 and 1881.

Locality.	1877.	1881.	Locality.	1877.	1881.
	Feet.	*Feet.*		*Feet.*	*Feet.*
tlet lock above Georgetown ...	19.72	16.73	Below Long Bridge.....	.....	11.20
ueduct Bridge.....	15.96	14.29	Arsenal Point.....	8.44	7.01
ek Creek.....	13.35	13.77	Giesboro Point.....	7.66	4.93
sbys Point.....	11.99	13.54	Navy-yard.....	7.73	5.01
ove Long Bridge.....	9.06	12.26			

FLOOD OF JUNE, 1889.[a]

June 2, 1889, there occurred the greatest freshet in Potomac River which there is any authoritative record. The Potomac at Harpers erry rose to the height of 34 feet above the low stage. The water as at one time 2.8 feet above the rails of the Baltimore and Ohio ailroad on the bridge and 6.8 feet higher than the freshet of 1877. t Great Falls the maximum height was 16 feet above the top sur- ıce of the coping of the dam, 4 feet higher than in the freshet of 1877. t Chain Bridge it was 43.3 feet above tide level. The freshet was receded by strong southeasterly winds, which made the tides at ıis point unusually high.

Observations were taken while the freshet was running to deter- ıine the levels above low water at various points from Chain Bridge own to Arsenal Point. The freshet attained its maximum height at bout 10 a. m. on June 2. At that time the height of the water ırface above low water at Chain Bridge was 43.3 feet, at Aqueduct ridge 19.5 feet, at Easby's wharf and at the sewer canal 13.3 feet, t Long Bridge 12.7 feet, and at Arsenal Point 11.1 feet. It was ithin 3 feet of its maximum height for a period of about twenty-four ours and within 6 feet of it for about thirty hours. After the river egan to fall it fell rapidly, but for more than twenty-four hours it as too high for the sewers in the low part of the city to discharge ieir contents. Hence if a heavy rainfall had occurred during this eriod the sewers could not have carried off the rain water at all, and still larger area of the city would have been flooded. The highest oint reached by the water at the sewer canal at the foot of Seven- enth street was 13.26 feet. Before this height was reached the

[a] Chiefly from Ann. Rept. Chief of Engineers, U. S. Army, 1889, pt. 2, pp. 985-986.

water backed up in the B street sewer and came into the street the sewer outlets. After the water rose above the level of B it came into the city from the sewers and from the river Great damage was done to private property in the city, as the on B street was in many places over 4 feet deep, and reached store doors on the north side of Pennsylvania avenue, between and Tenth streets. At B and Fifteenth streets the high water 1889 freshet was 3.2 feet above that of 1877 and 0.7 foot high in 1881.

The discharge area of the river at Aqueduct Bridge wh freshet was at its maximum was about 38,000 square fee velocity observations were taken, but on the assumption that Babb's estimate of 470,000 second-feet discharge at Chain Brid correct, the mean velocity at Aqueduct Bridge was about 12 per second.

Rock Creek, which enters Potomac River 4,000 feet below Aqu Bridge, was estimated to have a maximum discharge of 20,0 25,000 second-feet during the night of May 31 to June 1, 1889.

SLOPE OF POTOMAC RIVER.

The fall of the Potomac below Harpers Ferry is about 245 feet. this about 90 feet occurs in a short distance at Great Falls (Pl. and if this be subtracted the fall in the remaining distance is fo to average about 2.5 feet per mile.

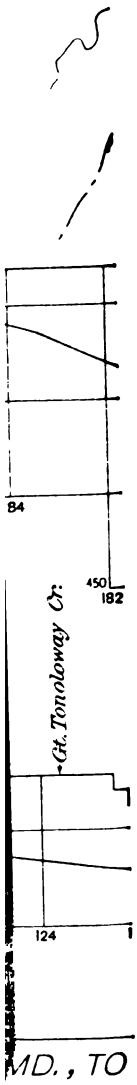
As a water-power stream the principal disadvantage of the P mac is the great variability of its flow. Good rock foundations dams can generally be found at small depth, the banks are as a favorable, and there are several sites where large falls could be dered available. Building materials are generally obtainable, facilities for transportation are excellent. A very insignifi amount of power has been developed.

Slope of the Potomac River.

[Pls. V and VI.]

Locality.	Distance from mouth.	Elevation above tide.	Distance between points.	Fall between points.	Fa mi tw po
	Miles.	*Feet.*	*Miles.*	*Feet.*	
Georgetown	0.0	0			
Harpers Ferry	61.5	245	61.5	245	
Shepherdstown	71.0	280	9.5	35	
Dam No. 4	85.0	319	14.0	39	
Dam No. 5	107.0	357	22.0	38	
Cumberland	185.0	610	78.0	253	

y Springs



THE CHESAPEAKE AND OHIO CANAL.[a]

By Horatio N. Parker.

idea of building a chain of internal improvements to connect otomac with the headwaters of the Ohio was conceived by e Washington, whose life had made him thoroughly familiar he country. In 1748 he was active in the organization of the Company, which was formed to trade with the Indians west of lleghenies, and whose charter made it incumbent on the stock- s to settle a certain number of families in the Ohio Valley. His st in that company, his expedition to Fort Duquesne in 1753, nally, his connection with the Braddock expedition of 1754 con- l him that it was imperative to establish water communication he West. Accordingly, in the fall of 1774, he procured the e of a law by the general assembly of Virginia, empowering ndividuals as were disposed to embark in the enterprise to open otomac so as to render it navigable to Wills Creek. In a letter ferson dated March, 1774, he said that the project was in good and would have been in an excellent way had it not been for position of the Maryland assembly, which was supposed to be ated by Baltimore merchants, who feared the consequences of transportation to Georgetown. The outbreak of the Revolu- nterrupted his plans, though he seems always to have had this m on his mind, for a little before the close of the war he left ontinental camp at Newburgh and made a long and perilous y up the Mohawk Valley with a view of determining the prac- lity of a water route to the West through that valley, returning ced that the great rival route to the Potomac would be through York. With the close of the Revolution, the problem became acute than ever, for it seemed likely that unless quick and communication could be established with the territory west of lleghenies it would ally itself with the Mississippi Valley inter- nd be forever lost to the eastern colonies. Washington strove se Virginia and Maryland to meet the problem, with the result he Potomac Company, incorporated by Virginia and confirmed aryland, was organized May 17, 1785. So far as known, the inutes extant are now in the possession of the Chesapeake and Canal Company and are of the meeting held May 30, 1785. e Washington was its first president, but his services were ed by his country and he was compelled to resign to accept the lency of the United States. The Potomac Company was only rately successful under the immediate presidency of Washington, hen it was deprived of his counsels it became markedly less

a. G. W., Early development of the Chesapeake and Ohio Canal project: Johns Hopkins udies in Historical and Political Science, series 17, Nos. 9-10 and XI, 1899.

efficient, and finally with his death lost the confidence of the public. However, it accomplished much work during its existence. At th time it was organized little more was expected of it than to rend the Potomac navigable from Georgetown to Cumberland, from whi point it was thought to be an easy matter to connect with the wate of the Ohio by means of a well-built road. The chief obstacl encountered in descending the Potomac were five in number. T first of these was at House Falls, 5 miles above Harpers Ferry, wh a canal 50 yards long, with a total fall of 3 feet, was built. The seco difficulty was at Shenandoah Falls, immediately above Harpers Fer and was overcome by a canal 1 mile long, with a total fall of 15 fe At Seneca Falls a third canal, three-fourths of a mile long, with a to fall of 17 feet, was constructed. To this point no locks were fou necessary, but at Great Falls they were used in connection witl canal 6,000 feet long on the Virginia shore. The fifth and last car built for passing Little Falls, was on the Maryland shore, and v over 2 miles long, with a total fall of 37 feet.

The charter of the company originally provided that the work which it was organized should be completed in three years. It s became evident that it would be impossible to finish the work in t period, and the general assemblies of Virginia and Maryland passed act extending the time. Five such acts were passed by the Maryl legislature and ten by that of Virginia. Finally, in 1819, after ex ing thirty-five years and spending $700,000, the Potomac Compa applied to the board of public works of Virginia for relief. T board ordered Thomas Moore, its chief engineer, to make a survey the river with a view of locating a canal in its valley, a policy s gested by the board to the general assembly of Virginia in 1816.

Moore's work was begun on June 30, 1820, and in his report da December 27, 1820, he stated that the construction of the canal v practicable, and estimated the cost at $1,114,300. The board tra mitted this report to the governor of Virginia and he sent it to general assembly, which adopted a resolution authorizing the g ernor to appoint a committee to cooperate with a similar appointed by the governor of Maryland to examine into the affair the Potomac Company. The committee met in Georgetown July 1821, and found the Potomac Company bankrupt. Having satis themselves that there were no means available for opening Potomac River to navigation, they believed the time had come recommend a continuous canal from tidewater to Cumberland, they proceeded to that city July 15, and spent the rest of the mo examining the river westward to Savage River. Having comple this work, under the guidance of Moore's survey of 1820, the comm sioners began the location of a canal whose construction they belie

would at once be undertaken by the States of Maryland and Virginia. Sickness among their engineers and finally that of Moore himself, September 18, compelled the abandonment of the work after it had proceeded 157 miles eastward from its beginning. Moore died and was succeeded by Isaac Briggs, who rapidly completed the work. For the basis of their estimate the commissioners adopted a canal 30 feet wide at the surface, 20 feet wide at the bottom, and deep enough for 3 feet of water. Its cost was estimated at $1,574,954. The general assembly of Virginia passed a bill incorporating the Potomac Canal Company in February, 1823, but the Maryland assembly under pressure from Baltimore failed to do so; hence the project was held up for a time. The failure of the Maryland legislature aroused the friends of the canal and popular meetings were held in Virginia, Maryland, and Pennsylvania during the spring and summer of 1823. The sentiment in favor of the canal was found to be so strong that it was determined to hold a convention in Washington during the autumn for the purpose of uniting counsels, proposing legislation, and enlisting the cooperation of Maryland, Pennsylvania, and Virginia and especially that of the Federal Government, which up to this time had steadfastly refused to inaugurate a system of internal improvements. The convention met at Washington November 6, 7, and 8, 1823, and declared in favor of a canal. It appointed committees in each of the States interested to advance legislation and a central committee to give direction to all the various forces at work on behalf of the canal. Among other things, the central committee was empowered to memorialize Congress, gather all information possible, hasten the surveys, have commissioners appointed, open books for the subscription of stock, and, if occasion required, to call another meeting of the convention. This convention is a landmark in the history of internal improvements in the United States, for the Federal Government had up to this time held it to be unconstitutional for it to construct such works, but it now unshackled itself from this impediment and entered into the canal project heartily. The Virginia assembly passed an act incorporating the Canal Company in 1824. Maryland passed one, too, after the jealousies of the Baltimore merchants had been allayed by an amendment permitting them to tap the canal with a branch canal at some convenient point in Maryland or the District of Columbia. The United States confirmed the incorporation and President Monroe signed the bill March 3, 1825. Finally, Pennsylvania passed an act sanctioning the canal.

The United States engineers, under the immediate direction of Gen. B. Bernard, made an elaborate and detailed report, which was not ready for publication until October, 1826. They proposed a canal divided into the Chesapeake and Ohio Canal proper from tidewater to

Pittsburg, and the Ohio and Erie Canal from Pittsburg to Lake Erie. The Chesapeake and Ohio Canal proper was divided into three sections—the eastern section, from tidewater to the mouth of Savage River; the middle section, from Savage River to the Youghiogheny at the mouth of Bear Creek; and the western section, from the mouth of Bear Creek through the valley of the Youghiogheny to Pittsburg. The work done in preparing this report was very thorough and elaborate and necessarily consumed much time. The friends of the canal grew restive and in March, 1826, induced General Bernard to give out his estimate for the eastern section. It was, exclusive of the item of contingencies, $8,085,000, which was, of course, for those days, prohibitive. The central committee called another convention, which met in Washington December 6, 1826. This body decided to their own satisfaction that when the errors of the United States engineers in estimating labor and materials were corrected, the canal could be built for less than $5,000,000. At the instance of twenty members of Congress, President Adams ordered a new survey by James Geddes and Nathan S. Roberts, who reported that the eastern section of the canal could be built for $4,479,346.93. Subscription books were opened October 1, 1827. The beginning of work on the canal was an event. A party was formed in Washington and went to Little Falls, where, on the Fourth of July, 1828, President Adams removed the first spadeful of earth, and speeches were made by prominent men to the crowd which had assembled to see the ceremony.

The company's charter required 100 miles of canal to be built in three years. Contracts were closed for 43 miles of the canal before March, 1829, and soon the whole 48 miles between Georgetown and Point of Rocks was under contract. By May 1, 1829, work had been done on all five "residences" into which the section had been divided. However, labor proved scarce, and it was found necessary to import it from Europe. Sickness broke out among the men, who contracted fever in the valley, and some of the contractors were compelled to suspend operations. It was late in October before the various gangs were all in good condition, but the winter proved an open one, and it was possible to continue the work far into it. The men proved disorderly, and the laws of those days were not stringent enough to deal with them promptly, so that ultimately the importation of foreign labor by the company was abandoned. The canal from Seneca Creek to a point within sight of Georgetown was completed in 1831. In the meantime, about January, 1828, the canal company became involved in a suit with the Baltimore and Ohio Railroad. This railroad had the active support of the Baltimore merchants, and the first spadeful of earth which marked the inauguration of work on it was removed by James Carroll, of Carrollton, on the very day and only a few miles from the spot where President Adams celebrated the beginning of work *on the Chesa*peake and Ohio Canal. By its charter the Chesapeake

and Ohio Canal Company had obtained a right of way for a canal on the Maryland bank of the Potomac from Washington to Cumberland. By its surveys the railroad was compelled to gain the Potomac at Point of Rocks, 12 miles below Harpers Ferry, and follow the river to the latter point; otherwise a tunnel would have to be built under the mountain spurs, a financially impossible alternative. The canal company now sought to exclude the railroad from laying tracks between Point of Rocks and Harpers Ferry on lands to which it claimed prior rights. The suit was finally decided in favor of the canal company in 1832, but by that time it was bankrupt and Federal aid had been withdrawn. Such a predicament offered an opportunity which was successfully utilized by the Baltimore and Ohio Railroad to complete its tracks to Harpers Ferry. After a series of compromise proposals by the railroad to the canal company had been refused, the Maryland legislature took up the matter. May 9, 1833, a compromise was effected by the passage of a law calling for the joint construction of a canal and railroad through the disputed territory. The compromise cost the railroad heavily, for it was compelled to subscribe for 2,500 shares of the canal company's stock ($266,000), and the canal company built the road through the disputed territory (Point of Rocks). In 1834 the railroad completed the road to the Maryland side of the Potomac, opposite Harpers Ferry, where it was compelled to stop, for the agreement signed by the two companies demanded that the railroad should not be built across the Potomac until the canal should have been completed to Cumberland, if that was done within the time named in the charter—1840. At the time of the compromise, in 1834, Maryland came to the rescue of the canal with a loan of $2,000,000. This was soon exhausted, and $3,000,000 more was appropriated by the State June 4, 1836, but on condition that the Baltimore and Ohio Railroad be allowed equal rights between Harpers Ferry and Cumberland. This enabled the railroad to complete its line before the canal was finished. The summer of 1837 found the canal completed only to Dam No. 5, 127 miles from Georgetown. The next 27 miles of the canal, to Dam No. 6 at Great Cacapon, were in process of construction, and the last 50 miles, from Great Cacapon to Cumberland, were under contract. More funds were needed, and the general assembly of Maryland in 1838 advanced an additional amount of $1,375,000. By 1841 the waterway was completed only to Dam No. 6, and both the canal and the State of Maryland were in financial difficulties, so that further aid was not given until 1844, when the State of Maryland permitted the company, under certain conditions, to issue bonds to the amount of $1,700,000. With the funds thus raised the canal was completed to Cumberland in October, 1850.

Since its completion the canal has not been prosperous. In 1877

the works of the canal were seriously damaged by a freshet, and this provided an excuse to burden the canal with more debt by issuing additional bonds, which was done with the consent of the State of Maryland. In 1889 another freshet did even greater damage; and as those in charge of the canal had no funds with which to pay for repairs, it was left in this condition for two and one-half years, during which time the elements added to the damage and increased the cost of reconstruction.

At this time a movement was begun to dispose of the canal to certain railroad interests, but the bondholders of 1844 asserted their rights and began proceedings to get possession of the canal. As trustees they were given control for a certain number of years on condition that they would repair it, retire the bonds of 1878, and carry out other conditions imposed by the court. Apparently the trustees have satisfied the court of the feasibility of their plans, for the period given them to operate the canal has been extended from time to time and it is still in their possession.

To-day the canal between Georgetown and Cumberland lies on the Maryland side of the Potomac and pursues the immediate valley of the river to a point 1 mile below Pawpaw, where it passes through a spur of Town Hill by means of a tunnel 3,636 feet long and of circular cross section 27 feet across. This tunnel saves about 6 miles. The total rise from the level of midtide at Georgetown to the Cumberland basin is 609.7 feet. This ascent is broken by 74 lift locks and a tide lock that connects Rock Creek basin with the Potomac. The canal has a depth of 6 feet throughout, and from Georgetown to Harpers Ferry, 60 miles, it is 65 feet wide at the surface and 41 feet at the bottom. From Harpers Ferry to Dam No. 6, 47 miles, the width at the surface is 60 feet and at the bottom 36 feet. From Dam No. 6 to Cumberland, 50 miles, the surface width is 55 feet and the bottom width 31 feet. The average lift of the locks is a little in excess of 8 feet, though there are thirteen 10-foot locks and four 6-foot locks. The locks are 100 feet long and 15 feet in the clear and pass boats carrying 122 tons of 2,240 pounds. The canal is fed with water at eight different points. The first is at the Beal mill race in Cumberland, which is connected by gates with Wills Creek at the dam near the tannery of the United States Leather Company. The enormous amount of sewage which this race receives is, to a large extent, deposited as sludge in the head basin of the canal. This action is probably facilitated by the nature of the water received at the second supply point, the head-gates of the canal. This water is, as a rule, largely from Wills Creek, mixed with considerable water from North Branch, though in times of low water the entire flow of both North Branch, above Dam No. 7, and Wills Creek goes down the canal. The Wills *Creek water is* heavily polluted by mine waters, and therefore con-

A. CHESAPEAKE AND OHIO CANAL ABOVE WILLIAMSPORT, MD.

B. POTOMAC RIVER AND CHESAPEAKE AND OHIO CANAL AT DAM NO. 5.

considerable quantities of iron and sulphuric acid, which are itating elements, as is the lime of North Branch. So great is cumulation of precipitated sewage in the head basin that the company finds it necessary to dredge it out every other spring. this is done the sludge is distributed over the towpath and ide of the embankment. It becomes very hard and most of it is in place, though some of it is carried off by the river. In the , after the water is drawn off from the canal, the contents of ce discharge into the head basin as usual, but instead of con- g down the canal, as when the canal is in use, they return to er near the foot of the basin and below Dam No. 7. This first is not properly a part of the works of the canal. The precipi- action continues for 51 miles down the canal to the third sup- int, Dam No. 6, where the water in the canal is said to be much than at Cumberland. Dam No. 6, below Greenspring, admits water, which to a large extent comes from South Branch, and is usually of better quality than the river water at Cumberland dilution greatly improves the water in the canal. From Dam to Dam No. 5 the distance is 29 miles. About 6 miles above No 5 the canal passes through what are known as Little and Big These were originally high-water channels of the river, which been incorporated into the canal. Big Pool is 2 miles long. ccurrence of these pools is noted, because the current through must necessarily be very small and so gives opportunity for ntation of material suspended in the canal water and also e they must add to the time it takes the water to complete its e from Cumberland to the river. The canal and the river unite mile above Dam No. 5 (Pl. VII, *B*), and in the half-mile stretch the dam the canal and river waters are thoroughly mixed. At No. 5 the canal resumes its separate course and a fourth point er supply is established.

m Dam No. 5 to Dam No. 4, the fifth point where water is ed by the canal, the distance is 21½ miles. About 4½ miles Dam No. 4 the canal reenters the river and continues united t for 3.3 miles to a point 6,000 feet above the dam. In this ce the waters of the canal and river have become thoroughly , and it is well to remember that this dam is but 67½ miles above Falls. From Dam No. 4 the canal continues 23 miles to Dam at Harpers Ferry, the sixth point of water supply. Dam No. a mile east of Seneca Falls and 40 miles below Harpers Ferry, seventh and last point of water supply until Dam No. 1 is d at Little Falls.

oughout its length the canal is built on the surface of the land receives little ground water; in fact, the water has a tendency p out through the canal banks and in places to make the farm

lands too wet to be successfully cultivated. The current in the canal is very variable, changing in its different sections and with the stage of the river. Perhaps it would be correct to assume a current of 1 mile an hour in normal sections. At times of flood portions of the canal are under water.

Two expensive aqueducts carry the canal over Conococheague Creek and Monocacy River. The myriad little runs that come down from the hillsides to the river are excluded from the canal by means of passages made for them beneath the canal through masonry culverts. Thus these streams find direct entrance to the Potomac, except three, which enter Big Pool, and a few dry runs, the most important of which are one a little east of Monocacy River, one just above Harpers Ferry, and one 2 miles below Dam No. 6.

Every winter the water is drained off from the canal and its service discontinued. The length of the canal season is usually eight to nine months, and repairs are made every spring before the canal is reopened. It is not found necessary to clean out the canal on account of suspended matter deposited during the season's use, but certain points on the canal need rather frequent dredging because of earthy material that is brought in over its banks by water flowing over cultivated ground and in other ways. The canal company has no sanitary regulations and the crews of canal boats use the canal as a receptacle for feces and for kitchen offal. A few of the privies of the lock keepers overhang the canal, but the feces do not get into the river except in times of freshet. The canal company has succeeded in abolishing all but two or three of the other privies which overhang its line, and these, it is expected, will soon be removed. During the season of 1905 but one man employed on the canal boats was known by the officials of the company to have suffered from typhoid fever.

The canal company claims that by the terms of its charter it is entitled to all the water power of the river from Washington to Cumberland, but it has never developed it for manufacturing purposes, one reason being that a survey made to determine the amount of power which could be made available indicated that the outlook in this direction was not promising. A small mill at Williamsport and one at Seneca are the only ones above Washington to which power is sold by the company. At Dam No. 5 surplus water is sold for power purposes to a plant on the West Virginia side of the river, and the same people are contemplating the development of works at Dam No. 4. At Georgetown about 1,000 horsepower is sold. The water of the canal is not furnished to any community for domestic supply, though a few individuals here and there along the line use it for washing purposes.

STREAM POLLUTION, OCCURRENCE OF TYPHOID FEVER, AND CHARACTER OF SURFACE WATERS IN POTOMAC BASIN.

By HORATIO N. PARKER.

STREAM POLLUTION.

GENERAL ASPECTS.

The prosperity of the industries of the Potomac Valley, with its attendant increase of population, is justly a cause of congratulation to the several States within which the basin lies. Yet this success brings responsibilities that can not be shirked, but must be wisely met if growth is to continue and health and happiness prevail. In dealing with the new problems it should be borne in mind that the wealth of every region is limited. Resources which were extravagantly wasted when there were few to claim them have to be carefully husbanded when there is hardly enough to go around. Acts which may be viewed with indifference in a sparsely settled country become crimes in densely populated communities. No resource will be more seriously affected by changed conditions than water. It is strictly limited in amount, and therefore to injure any source which is valuable for manufacturing or domestic use is a spendthrift deed, sure in the end to increase the cost of living. For, one by one, the sources of pure water which are not too expensive to utilize will be preempted, and then will come the time when the supplies that have been ruthlessly damaged must be purified. It can be done, but it costs money. Water rates will rise, and then every man will have to decide for himself whether it will be more profitable for him to remain where he has built up his business or to migrate to some place where the supply of water is yet unpolluted, or where the citizens have been forehanded enough to keep, by well-considered legislation, the cost of purifying their water supply within reasonable limits.

Often before industry is crippled by bad water a town or city experiences epidemics of water-borne disease that result from an impure water supply. This condition is brought about by contamination of the water by the feces of persons sick with Asiatic cholera or typhoid fever. Happily in this country outbreaks have generally been

limited to the latter disease. At first the policy of concealment is adopted by the afflicted community, and "malaria" is said to be present. Later, when suspicion arises that the trouble is something more serious, the terms "fever" or "typhoid malaria" are used, and when the outside world can be no longer deceived by euphuistic names it is admitted that "there was some typhoid last year." By this time the degree of contamination in the supply has either become sufficiently great to produce typical cases of typhoid fever, or so many cases develop at one time that an epidemic is said to be present. Public opinion is aroused, the town is bonded for the construction of a new water supply or for purification works, and the tribute of human lives demanded by pollution is stopped.

Both sewage and industrial pollution may inflict great loss in the community by making its streams unfit for harvesting ice. The late Prof. Thomas M. Drown[a] showed that ice in freezing has a decided tendency to exclude impurities, but he found this action to be most marked in the layers that are formed by the slow growth of the ice downward, because the surface in its rapid congealing entangles suspended matter, particularly if the water is stirred up by the wind. Moreover, if the ice is frozen after surface flooding, which is frequently brought about intentionally by the harvesters, it will contain all the impurities of the water so added. In making artificial ice in the ordinary way the entire body of the water is frozen and all the impurities are concentrated in the last part of the cake to freeze. Hence an impure water is particularly undesirable for ice manufacture. Likewise, when shallow ponds freeze solid, the impurities are concentrated in the bottom ice.

The fact that ice forms in greater purity than its surrounding medium undoubtedly has permitted it to be obtained from questionable sources and still to be used with impunity. But outbreaks of typhoid fever have been attributed to polluted ice, and it is certain that a stained or ill-smelling ice is unsalable, so that consumer and producer alike suffer from river pollution. Indeed, probably most readers know of ice ponds which have had to be abandoned because the ice from them was no longer marketable.

The question how best to get rid of the wastes of human life and of the industries which are a part of it is a very pressing one. Every health officer is familiar with the subterfuges adopted to avoid the expense attendant on the proper disposal of these wastes. Very naturally, rivers have been seized on as the easiest way to solve the problem, because they passively accept all burdens given to their charge and carry them away. Indeed, water has been called the great scavenger, and not a few manufacturers regard the streams as natural sewers created by Providence for their use.

[a] Jour. New England Waterworks Assoc., vol. 8, No. 1, 1893.

Natural beauty has a distinct value, and those who mar it impair the resources of a country, for a discolored repulsive stream will not be utilized for recreation purposes, and a stinking one will not be featured in realty advertisements. The monetary loss to communities arising from severe pollution of the streams on which they are located is often very heavy, and the damage is reparable only at great expense.

The constantly increasing cost of food has become a serious factor in the development of the country. Dishes that were common on the tables of our fathers have become rarities to many and are entirely foregone by not a few. In spite of this we are carelessly curtailing our fish supply, as the filth poured into our streams and rivers drives the fish from their spawning grounds. Some streams they have quite abandoned; others they visit in decreasing numbers. It is true that we place large quantities of fry in various streams every year, but some fish—the sturgeon, for example—can not be perpetuated in this way.

It should be remembered that some one always pays for water pollution. If the laws are such that they relieve one corporation of caring for the wastes it creates, it is likely that they entail great expense on another. Thus a railroad which is compelled to use polluted water in its locomotives will in consequence have many repairs to make, and the increased cost of mileage caused thereby will have to be borne by those who travel and transport goods over the road. Similarly, if one man is unmolested in turning the effluent from his mill into a stream, it may drive his neighbor downstream to drill deep wells in order to introduce a new water supply into his works. Instances of this sort of thing might be multiplied, but it is enough to recognize the fact that though a river basin may lie in several States, as does the Potomac, its people are more closely bound together by its waters than are the inhabitants of a single State by the arbitrary boundary lines established for them. The silver river threads are direct lines of communication between each individual and every other below him on the stream. The offenses that he commits against the water are paid for by his fellow countrymen in the basin, and the bill is large or small according to the gravity of the transgressions.

INDUSTRIES DISCHARGING WASTES INTO THE STREAMS.

In order that a clear understanding may be had of the various wastes which enter the Potomac, a description of the manufacture of the principal products of the Potomac basin is subjoined.

LEATHER TANNING.

Pelts are divided into three classes, according to their size. Hides are skins from large and fully grown animals, such as the cow, ox, and

horse, and make heavy leather, such as shoe soles, belting, and trunk leather. Kips are the skins from yearlings of the above species or from undersized animals. Skins are obtained from small animals, such as calves, goats, sheep, and dogs, and yield a lighter leather, suitable for a great variety of purposes. The thickest and heaviest hides come from sparsely settled countries, and a hide varies in thickness and texture in different parts, being thicker on the neck and butt than on the flank and belly. The skin of the animal is made up of three layers. The first or outer layer is known as the epidermis, and consists of a dead layer which is continually being worn off and of a live layer which renews the dead layer as it wears away. To this epidermis the hairs of the animal are attached. The second layer, or corium, is the true skin, and the only part of the hide which is valuable in making leather. It consists of connective tissue composed of bundles of fibers which interlace somewhat closely on the under side, but are closely matted on the epidermal side. The third and inmost layer is a loose network of connective tissue, containing muscular fibers, fat cells, blood vessels, and sudorific glands, whose ducts pass through the corium and epidermis.

The pelts come to the tanner "green" (fresh from the slaughterhouse), wet, or dry salted (with the salt rubbed on the flesh side), or as dry hides. The dry hides are mostly imported from South America. Green pelts are usually washed in clear water to free them from blood and dirt; salted pelts, if not dried, are washed in several changes of water to remove the salt, which retards the action of the lime in the unhairing processes and also induces efflorescence (spewing) on the finished leather. Dried hides must be softened by soaking them in lukewarm water or in the liquor drawn from the soaking of a previous lot. The water dissolves a part of the hide substance and putrefaction soon begins, the liquor developing an alkaline reaction, owing to the formation of amines and ammonia, which give it a much more rapid softening action on the skin. Great care is necessary in using this "putrid soak," for it is likely to attack the hide itself. The time of soaking varies from two or three days to as many weeks, depending on the thickness and dryness of the hide and the age and temperature of the soak liquors. When the hide is soft enough to bend in a short turn without cracking, it is put into the "stocks," where it is pounded and rolled under heavy wooden mallets and rolls.

The character of the water used in a tannery is important. Soft water makes the skins thin and slim, which is desirable in light leather. Water containing calcium or magnesium sulphate "plumps" or swells the hide, thus exposing a larger surface to the action of the tan liquors, which is desirable for heavy hides. Water bearing carbonates of lime or magnesia gives trouble, because in the tan pits these salts are transmuted into tannates of lime and magnesia, and these rapidly oxidize in

ir into tan-oxalic and tan-melanic acids, which impart a reddish-
n color to the leather. Ferruginous waters can not be used in
ing, for the ferric salts combine with the tannin and produce a
k coloration of tannate of iron. Chlorides cause the hides to
l;" that is, to become thin and flabby. Perhaps this is due to the
ter solubility of the coriin in saline liquors. If used for washing
: the liming, water having temporary hardness tends to fix the
among the fibers in an insoluble form, thus causing the leather
e harsh on the grain and producing color spots because of unequal
sits of tannin and coloring matters while the skin is in the tan

If the water contains organic impurities it may have an acid
re and cause the hides to "fall" after liming. Highly polluted
rs can not be used in tanning, because the putrefactive bacteria
ck and destroy the hides.

ne "putrid soak" and the liquor from the washings of the green
salted hides are uniformly discharged into the nearest creek, being
rded by the tanner as so much dirty water and nothing more. As
atter of fact, this liquor contains much salt and organic matter.
putrid soak may also contain cresol or other preservatives, which
sometimes used in conserving the dried hides. The soak liquors
be the means of spreading anthrax. An outbreak of this disease
rred in Pennsylvania in the spring and autumn of 1897 and was
stigated by Ravinel. Three tanneries operated by the United
es Leather Company were involved. It was found that each of
1 had received a part of a cargo of hides from Chicago, and it was
ved that they were the fomites which spread the disease. In one
ne tanneries twenty-four cases of "malignant pustule" developed,
of which proved fatal. Below this tannery 12 head of cattle
, some of the deaths occurring as much as 10 miles downstream.
ll, 12 men and 60 head of cattle died near the tanneries. The
were without exception operatives, while the cattle were on pas-
s watered by the streams carrying tannery effluents.

acteriological experiments were conducted which led to the con-
on that the process of tanning as ordinarily carried out does not
ay way protect the operative from infection by the anthrax germ.[a]
ne second step in tanning is the "unhairing" of the hides, and this
complished in two ways—either by sweating or liming. Green
s are usually sweated by allowing them to hang in a room where
emperature is 70° F., and permitting disintegration to advance
ne point at which the hair can be readily removed mechanically,
beyond which the hide is injured by being itself attacked. Before
ng to the next stage, treating with tannin, sweated hides must be
mped" by immersion in dilute acid, such as hydrochloric acid.
ning, the skins are laid in a vat or pit with milk of lime, which

[a] Trans. Am. Pub. Health Asso., vol. 24, 1899, p. 303.

loosens the epidermis and forms a soap with the fatty matter. It al dissolves the coriin—the intercellular substance which fills the spac between the bundles of fibers—loosening the fibers, which swell a plump the hides. Lime is used in excess in amounts varying fr half a pound for a small, light skin, to 4 pounds for a heavy one. T vats or pits when prepared to receive the skins are called limes. T skins are turned over and worked about at intervals while in the v Heavy hides, which are to form a stiff, hard leather are limed for a few days, but when a soft, elastic, and pliable product is desired process is continued for fifteen to twenty days or longer. Warn the limes to 85° or 90° F. hastens the action very much, but ca the skins to "fall." Dried hides are often treated by adding sod sulphide to a thick cream of lime, forming a paste which is sprea the hair side of the skin, after which the hide is folded together, v the hair can be easily removed after a few hours. This pr depends on the formation of calcium sulphide, which dissolves the in contrast to the process employing lime alone, which dissolve hair sheath as well as the intercellular substances and softens the dermis, which comes off when the hair is scraped. Sometimes sodium sulphide is added in solution to the milk of lime instead of l applied as a paste. Still another process for unhairing dried hi the adding of arsenic sulphides to the amount of 10 per cent o weight of lime. This forms calcium sulfarsenite ($HCaAsS_3$), whi a very rapid depilatory. The waste from the lime pit is frequ turned directly into the nearest stream, but the best tanners util as a fertilizer by running it into pools, where it is allowed to evapo The accumulated material is applied to the land, on which it seer have a very good effect, probably on account of the large amou organic matter derived from the hides, though the lime itself m some cases be valuable to neutralize acid soils. It is not likely those "limes" which contain arsenic could be used in this ma and they cause much trouble in those places where entire tan wastes are treated by intermittent filtration, because they kill the teria, which, of course, destroys the action of the filter bed. wasteful and unnecessary to dispose of the lime waste by runni into a stream. It should always be recovered as a fertilizer.

When the hide has been unhaired by one of these processes, washed, and the washings are added to the liquors wasted fron lime vats; it is then ready for the "beam," a peculiar sloping b or table on which the hides can be spread out and convenie worked. On the beam the hair and epidermis are scraped off a blunt knife, and the fatty tissues are removed with a sharper After trimming off the waste parts of the skin it is thoroughly wa and is usually again scraped on the beam ("scudded"), to rer as much of the lime as possible. The hair is sold for cheap

and blanket manufacture, or most usually is disposed of to plasterers. The flesh and partially saponified fat which are removed from the inside of the hide are collectively known as "fleshings," and are either dried and sold to glue manufacturers or are rendered and the fat sold for the manufacture of dégras. The liquor which results from rendering the fleshings is turned into the nearest watercourse, but it should go to the lime pool. From the beam house the hides which are not to be made soft and pliable go directly to the tanning liquors, while those skins to which it is desired to impart these qualities are "bated" or "puered." Bating consists in soaking hides in a mixture of dog or bird dung in warm water. This quickly becomes putrid and evolves hydrogen sulphide. By some it is claimed that the bate merely removes the lime from the pores of the hide, while others assert that it also takes away some of the coriin, thus leaving the fibers looser and allowing more perfect action of the tan liquors. The latter view seems to be more probable, for there is little doubt that the bacteria in the bate do feed on the hide substances. Moreover, the forms of tripepsin, pancreatin, etc., present undoubtedly have some function, for when used alone they will cause a "plump" skin to "fall." Also the ammonia salts formed probably assist in the solution of the lime and the skin. The process lasts from two to four days, according to the thickness of the skin and the temperature. It is largely dependent on atmospheric conditions, being much more rapid in warm, sultry weather, such as precedes a thunderstorm, when a few hours are often sufficient to injure the skin. At all times great care must be used and the skins stirred about frequently to prevent too great local action, which would produce thin places or holes in the leather. Many proposals have been made to replace the offensive bate with pure solutions of weak mineral and organic acids, but such substitutes have not been successful, the objection being that they make the leather harsh and of a bad grain.

To effect a complete removal of the lime the skins are passed from the bate into the "bran drench," an infusion of bran and water at a temperature of about 89.5° F. Acetic and butyric acids are developed and neutralize the lime. The wastes from the bate and drench are not large and should be utilized for fertilizer in the same way as the spent lime liquors. This, however, is rarely done, the custom being to turn them loose into some stream. Both the light and the heavy hides are now ready for the tanning process. There are three kinds of tanning—with tannin in any form (vegetable tannage), with metallic salts (mineral tannage or tawning), and with oils or fats (oil tannage). As only the first process is used by Potomac valley tanneries it alone will be described.

The tanning liquors are usually made by extracting finely ground chestnut-oak or hemlock bark with water. Hides treated with infusions of the former make a tough, durable leather known as oak-tanned; infusions of hemlock bark make a hard, stiff leather known as hemlock-tanned; a combination of the two produces union-tanned goods. Hemlock-tanned leather is of two varieties—acid and nonacid. In oak, nonacid, and union tanning the processes are essentially the same, and so only oak tanning and acid hemlock tanning will be described.

Good tanning material yields other extractive matters than tannic acid when treated with water. They are nontannins and consist mainly of sugars, gums, resins, and coloring matters, which assist in tanning in several ways. Some of them are directly absorbed by the skin, increasing its weight and solubility; others set up fermentation in the tan pit, producing organic acids, which assist in the formation of a leather of good body and weight. Tannins derived from gallic acid cause a white efflorescence (ellagic acid) on the leather, while those of the protocatechuic-acid group deposit red coloring matters (phlobaphenenes). The tan liquors are prepared by systematic lixiviation of the ground tan stuffs. Warm water is generally used for extracting the ground bark, and the process is usually carried on at the top of the tannery, so that the liquor can be readily distributed about the works, either to pits which are to be strengthened up or to those which are to be filled anew. Prepared tanning extracts are often used, either alone or in conjunction with the liquor obtained by extracting the bark at the tannery. These prepared extracts are frequently adulterated with glucose or molasses, so that tests with the barkometer—a special form of hydrometer used for determining the strength of tan liquors—are of no value. In tanning, the hides ("butts") are first hung from frames in vats ("suspenders") containing weak or nearly spent tan liquors from a previous lot. There they are mechanically agitated in order that they may take up the tannin evenly. Weak liquors are used at first, because strong ones would harden the surface of the butt and prevent the thorough penetration into the interior of the hide. This partial tannage strengthens the hides sufficiently for them to withstand the rough usage which they receive when transferred to the "handlers"—vats where the hides lie flat in a pile and are worked over ("handled") once or twice a day for a month or six weeks. There are several of these vats, and the hides are treated systematically first with weak and then with stronger liquors, after which they are put into the "layers"—pits filled with alternate layers of hides and ground bark and velonia, etc. Strong liquor ("ooze") of 35° barkometer is run in until the hides are submerged, and the pit well is then covered with ground bark to *exclude the* air. After eight or ten days the hides are taken out,

ubbed clean, and "laid away" again in fresh tan and stronger liquor, n which they remain a longer time. This process is often repeated, ne time consumed being on an average from eight to ten months. 'he process may be hastened by keeping the liquor in the tan pit in onstant circulation, or by using pressure to force the liquor into the kins, or by using strong extracts and continually moving the skins. s a rule, however, rapid tannage makes the hides lacking in sub-ance ("hungry") or brittle. In oak tanning, of sole leather, sually one hundred and twenty to two hundred days are consumed. 'hen the hide comes from the lay-away vats it is covered with a bloom" of ellagic acid, which sole-leather and harness-leather tan-ers remove with "scouring machines" to improve the appearance ' the goods. Scouring requires considerable water, which is stained d by the process. The waste is uniformly turned into the nearest ream and of course discolors it.

In acid hemlock tanning, the hides are first colored with a weak olution of tannin, after which they are abnormally swelled by being ut in a 10 to 30 per cent bath of sulphuric acid, where they remain or twenty-four to forty-eight hours. They are then put in a stronger annin solution and are finished in one hundred and sixty days.

The waste tan liquors or sour bark liquors, as they are usually ermed, are usually the most voluminous wastes from a tannery and onsist of a small percentage of tannic and gallic acids, with consider-able organic matter in suspension. They are usually discharged into a stream, either constantly or in large volumes, at regular intervals, and are always strong enough to color the water a deep red and to stain the banks and bottom of the stream. The volume is so large that this waste is difficult to treat. The most successful way of deal-ing with it known at present is that devised by the Massachusetts State board of health; in this process it is mixed with city sewage and treated by intermittent filtration. Such a method of treatment could not be applied in the Potomac drainage area, because the tanneries are located in places where city sewage is unavailable. Some tanners claim that they have practically no waste of sour bark liquor, because they maintain a constant circulation of the liquor through their works; that is, when the liquor is so depleted as to be of no further use for tanning it is run back onto fresh ground bark, where its strength is renewed. In tanneries of this type it is generally found necessary to waste the tan liquor which first receives the hide after it comes from the "beam," as the lime salts extracted at that time are thought to be sufficient in amount to affect large volumes of tan liquor, making it turn out a brittle leather. Many tanners refuse to adopt this con-tinuous-circulation process, claiming that they can not get the kind of leather they are in the habit of producing by its use.

After hides are tanned they are washed in clear liquor, and when they have dried somewhat they are oiled on the grain and hung on poles in the drying loft. When about half-dry they are laid in piles ("sammed") and allowed to sweat, so as to facilitate the "striking" operation which follows; this is done by hand or machinery. They are then allowed to dry a little more, and finally they are rolled again, after which they are ready for the market, though in some factories the hides are colored on the grain side by a mixture of ocher with size and oil to give the leather gloss.

In the final finishing up of the leather—that is, in cases where hides are oiled or stuffed at the tannery—considerable oil escapes into the nearest creek, making it unsightly.

The spent tan bark, which formerly caused much complaint when it was discharged into the stream and allowed to accumulate about the tannery, is now disposed of without trouble, because it has been discovered to be a valuable fuel and is used for such both in extract plants and tanneries. But a single instance was found in the course of this investigation where any trouble was caused by spent tan bark. This was at Moorefield, where a tanner had accommodated the proprietor of a gristmill by furnishing him spent tan bark to stop the many leaks in the old dam which furnished power to the mill. It was said that the stream was considerably discolored in consequence.

To sum up the wastes from the processes of tanning, most of them are putrefactive and therefore add materials to the stream which make it capable of sustaining bacterial life, and for this reason their presence is objectionable. Moreover, when all the wastes are turned into a stream, unless it is a very large one, they discolor it, making it unsightly and also cause a great nuisance by the odors of decomposition which rise in the stream and in the vicinity of the tannery. Where tannery effluents are discharged into streams polluted with mine waters large quantities of tannate of iron are formed, thus literally converting the waters into rivers of ink. It is needless to say that this condition is vigorously resented by all who are unfortunate enough to be brought into contact with it.

MANUFACTURE OF TANNING EXTRACTS.

Tanning extracts are made by leaching various finely ground tannin-bearing materials, such as sumac and chestnut-oak wood, in water and then evaporating the solution to a thick sirup. It is perfectly possible to manufacture the extracts without offense, but leaky vats produce extensive discoloration of the streams into which they discharge, and in certain places this causes much complaint. An entirely negligible amount of tannin escapes in the condenser water from all extract factories. Carbonate waters are unsuitable for the *manufacture* of extracts for use in dyeing, as they form "lakes" with

he dyes, and consequently loss of coloring matter ensues. The con-entration of large volumes of the tannic juice made with carbonate waters causes the precipitation of normal carbonates of lime and magnesium, which are harmful in the tan pits. Iron in the water combines with the tannic and other acids extracted, forming ferric compounds, which give dark-blue, olive, and green precipitates that not only discolor hides, but waste the tannin-forming materials from which the extract is made. Moreover, compounds of the tannic acids with salts of the alkaline earths result when water containing appreciable quantities of these salts is used in extracting. Thus the extracts produced are poorer, and the process of manufacture is slower, because the deposits prevent the water from penetrating into the woody fiber.

MANUFACTURE OF WOOD PULP.

There are three common ways of manufacturing wood pulp, known as the mechanical, the soda, and the sulphite processes. The first two of these are used in the Potomac Valley and will be briefly described.

Mechanical wood pulp.—The bark is first shaved off the wood and then the knots are removed, after which it is cut up into blocks, gaged to the width of the stones used in grinding. These stones are usually imported from Scotland and are of sandstone, covered over three quadrants with an iron casing, the fourth being left bare. The faces of the stones are kept rough, as they revolve, by a steel roller studded with points, which is pressed against them. In addition to this, two sets of channels, which cross each other in the center of the stones, are cut into them about one-quarter of an inch deep at distances of 2 to 3 inches. They carry the pulp to the sides of the stones and give them increased grinding surface.

The wood is forced against the revolving stones, over which a water jet plays, and by means of screws worked by a suitable gearing is held at he steady pressure necessary to insure a pulp of uniform character. The water jet carries away the pulp as fast as it forms, first to the ake, which catches the splinters that have escaped grinding; then he stream of pulp passes through the sorters, cylinders 3 feet long nd 2 feet wide, of wide-meshed wire cloth, which separate the nsufficiently disintegrated fragments. The fibers that are retained re subsequently reduced to the proper size in the "refiners," which re cylinders of sandstone, one above the other, the upper one of hich revolves. The material that passes the refiners is again reened and returned to the pulp stream, from which the sorter is nducted through a series of screens of gradually increasing fineness, id thus graded into different qualities. The ground and sorted pulp, ixed with water, flows into a tank in which revolves a cylinder vered with wire gauze. The water passes through the cylinder,

while the pulp adheres and is delivered to an endless belt, which carries it to a pair of squeeze rollers. The pulp is compacted in passing through these rolls and sticks to the upper one, from which it can be readily removed when it has become sufficiently thick. Finally, it is cut into sheets, which are pressed into boards of convenient size for transportation. Mechanical wood pulp is suitable only for the cheapest kind of paper, such as newspapers, because the fibers are short and do not felt together well, hence the paper lacks strength; moreover, it yellows readily, as the lignin and resin which the pulp contains predominate. Mechanical wood pulp is much used as a filler in manufacturing certain kinds of paper.

No chemicals are used in this method of pulp production, so that there are no liquid wastes to produce noxious effects on streams and lakes, but the shavings and the finest fiber that escape cause bitter complaint. (See Pl. VIII,*B*, p. 222.) They soon become water-logged and sink, accumulating rapidly on the bottom of the stream, with the result, as one old fisherman aptly put it, "that the bedding, feeding, and breeding grounds of the fish are destroyed." The effect on the spawn is particularly bad, for the motion of the water rolls the material over the eggs and smothers them. Besides, in time the mass begins to rot and then certain gases are liberated, which also may have a harmful effect on fish life.

It is wholly unnecessary to dispose of the shavings in the streams, for they can be burned at no great expense, and the laws which prohibit sawmill pollution should be extended to cover mechanical pulp mills.

Soda wood pulp.[a]—In the manufacture of soda wood pulp the logs are cut to thin shavings and are treated for about eight hours in digesters with a caustic-soda solution at a pressure of about 100 pounds of steam. After being washed the pulp is bleached by a solution of chloride of lime, the process consuming from six to eight hours. When the bleaching is complete the mass is reduced to a more fluid state by the addition of water and is pumped into large vats with porous bottoms through which the water runs. When the bleached pulp is thoroughly drained it is pumped into a large storage vat, from which it is taken to a cylinder machine and is felted in the usual manner.

The soda solution drained from the wash pans is treated in order to recover the soda. It is evaporated and the concentrate is turned into rotary furnaces where the lignin and other organic materials are burned off. The residue is composed almost entirely of carbon and sodium carbonate and is known as black ash. This substance is then passed through a bleaching process, the liquid or recovered soda

[a] For a full description of the processes used in the manufacture of soda wood pulp see Water-Sup. and Irr. Paper No. 121, U. S. Geol. Survey, 1905, pp. 24–33.

(sodium carbonate) being conducted to the causticizing plant, while the sludge, known as black-ash sludge, remains in the tanks and is subsequently washed out with water and carried away as waste.

The soda recovered in the form of carbonate is converted to a hydrate or caustic soda by the application of caustic lime. The result is a sodium hydrate or caustic soda in the solution, while the calcium carbonate, or common lime, remains in the bottom of the container as a heavy sludge. The solution is drawn off for use in the digestion process. Considerable soda remains in the lime sludge after causticization, and repeated washings are necessary to recover all the soda. When the washings are completed the lime sludge is discharged.

The solution used to bleach the pulp is prepared by the treatment of chloride of lime in solution tanks fitted with rotary agitators. The bleach is drawn off from the tank and the sludge is again treated in order to utilize all the bleaching solution, and the lime sludge left after the second treatment is discharged as waste.

The important wastes are (1) the black-ash sludge, which is mainly carbon, with a small percentage of undissolved carbonate of soda; (2) the lime sludge ($CaCO_3$) from the causticizing process, which also contains a little soda; (3) the lime sludge ($CaCO_3$) from the bleaching process, which contains a very appreciable amount of chlorine. To these should be added the considerable amount of wood fiber that escapes from the mill, and the bits of wood from the chipper. In some factories the various sludges are sedimented with good results, large quantities of suspended matter being thus kept out of the streams.

At Luke, Md., there are no sedimentation beds and North Branch receives the entire waste of the West Virginia Pulp and Paper Company, which, in addition to the effluents above enumerated, contains alum, kaolin, a little ultramarine blue, and size. The effect of this pollution on North Branch is to increase the chlorine and alkalinity of the water. But these elements serve to neutralize the acid waters of Georges Creek, with good results.

MANUFACTURE OF ILLUMINATING GAS.

Coal gas.—Coal gas is made by the destructive distillation of bituminous coal. The by-products of the process are ammoniacal liquors, tar, and coke. In large plants the first of these is sold to ammonia works; the second to works for recovering coal-tar products, and the third is used for fuel in the plant or sold for domestic consumption. Small works are compelled to waste the coal-tar products and the ammoniacal liquors into the nearest watercourse, unless they are sufficiently near to recovery plants to make it profitable to ship them.

The retorts in which the coal is distilled are of fire clay, and in the various works are differently designed. The gas is led from the mouth of the retorts by vertical pipes to a pipe dipping downward into a hydraulic main and extending beneath the surface of the water which partially fills the main, the back flow of gas to the retorts being thus prevented. The hydraulic main is a long covered trough to which all the retorts are connected. In it most of the tar and oily products condense beneath the water and flow to the tar wells, while the water itself dissolves most of the ammonium salts out of the gas.

The hydraulic main leads the gas to the condenser, which is constructed in several ways, but always with the purpose of cooling the gas in long iron pipes, whose lower ends dip beneath the surface of water held in an iron tank. The lowering of temperature effects a condensation of those constituents of the coal gas which at ordinary temperatures are not volatile, and forms a tar of them, which sinks to the bottom of the tank and flows to the tar well. At the end of the condenser is an exhauster, which keeps under suction the gas in its passage from the retorts to the end of the condenser and puts the rest of the plant under pressure.

From the condenser the gas is passed by the exhauster into the tar extractor, a short tower filled with many horizontal, perforated plates, in passing through which the gas is relieved by friction of its last traces of tar. It then goes to the scrubber, where it comes into contact with thin films of ammoniacal liquid from the hydraulic main or condenser, which trickles over pebbles, coke, etc. This liquid absorbs from the gas some of the carbon dioxide and hydrogen sulphide, which combine with the ammonia. From the scrubber the gas goes to the washer, where clean running water removes the ammonia.

The gas next flows to the purifiers, where its sulphur compounds are taken out. The purifiers are covered iron boxes which hold on a grating either slacked lime or hydrated ferric oxide. The gas enters from below and passes through the lime or iron, yielding up its sulphur as it does so. Usually the gas passes through four purifiers in succession. The lime in addition to removing the sulphur compounds combines with the carbon dioxide which the gas carries and which is an undesirable constituent. The iron extracts only the sulphur. In time both iron and lime become exhausted, being converted by the sulphur into very ill smelling sulphides. The iron can be renewed two or three times by exposing it to the air, which oxidizes it. In the end, both substances have to be disposed of, which is done by dumping them into the nearest stream, or sometimes by selling them. From the purifiers the gas goes through the meter house into the holders, from which it is delivered to the mains. The wastes in the manufacture of coal gas in works of considerable size favorably situ-

l for shipment are all recovered, because the by-products obtained
n them are valuable. Many small plants scattered about the
ntry find it impossible to ship these products at a profit and there-
they turn them into the nearest watercourse, where they produce
ghly objectionable state of affairs. The light tars float as an oily
escent film on the surface of the water, giving it a disgusting appear-
e. The heavy tars sink to the bottom and foul the bed of the
am. The effect of the ammoniacal wastes is not visible, but
monium salts are good food material for bacteria and microscopic
anisms, and therefore the tendency of such wastes would be to
er their development. Moreover, gas wastes are believed to be
y fatal to fish, and even when present in quantities insufficient to
the hardy varieties, they impart a flavor of gas to the flesh which
pels their abandonment as food.

Water gas.—Water gas is produced by the action of steam on incan-
cent carbon and is composed mainly of hydrogen and carbon
noxide. It has a high heat value, but is a poor illuminant, and
refore it has to be enriched with various hydrocarbons, such as
ane, ethelyne, acetylene, and benzene, which impart to it the
essary light-giving quality. As these substances are yielded by
roleum, it is used to carburet the gas.

The manufacture of water gas is carried on in three chambers.
e first is called "the generator," the second "the carburetor," and
third "the superheater." The chambers are circular, the super-
ter being the tallest. Both it and the carburetor are lined with
brick and are filled with a checker work of the same material.

nthracite is put into the generator and brought to incandescence
a blast of air which is introduced at the bottom. Thus is liber-
l a gas known as "producer gas," which consists mostly of nitro-
carbon dioxide, and a little carbon monoxide. This producer
escapes into the top of the carburetor, and in circulating down
ugh it is partly burned by a blast of air introduced near the top
he chamber. This combustion makes the brickwork hot. From
bottom of the carburetor the gas is conducted to the bottom of
superheater, where another blast accomplishes the complete com-
tion and raises the checkerwork to red heat, the gases finally
aping through a hood at the top of the chambers. When both
carburetor and superheater have reached the desired tempera-
e the air blasts are shut off and superheated steam is blown in at
bottom of the generator. This forms carbon monoxide, or water
, which passes into the carburetor, where it meets a stream of oil
roduced at the top. The oil is decomposed into illuminants which
c with the water gas and pass into the superheater, where they
completely fixed as incombustible gases.

From the superheater the gas is led to a holder, from which it passes through a purifying apparatus involving principles identical to those that obtain in the manufacture of coal gas.

Water gas is very poisonous owing to the large percentage of carbon monoxide that it carries, and much of the harm that is commonly attributed to so-called sewer gas comes from defective gas piping and inefficient burners in conjunction with the water-gas service.

The tar from the manufacture of water gas is of less value than that from coal-gas production. It can be recovered and used as fuel in the plant, thus obviating the objectionable effects, similar to those of coal-gas tar, which result when the waste is turned directly into a stream.

MANUFACTURE OF AMMONIA.

The chief source of ammonia is the gas liquor from the hydraulic mains and scrubbers of coal-gas works. By destructive distillation the nitrogen contained in coal is largely converted into ammonium salts, the principal of which are the carbonate, sulphide, and sulphohydrate, which are volatile in steam, and the sulphate, thiosulphate, sulphite, sulphocyanide, and ferrocyanide, which are not. All of these compounds, together with free ammonia, are found in gas liquor.

The gas liquor received at the ammonia works is allowed to stand in order that the tar may settle out, and then clear liquor is distilled to separate the ammonia. There are several forms of apparatus for this purpose. In the simplest of them the liquor is heated in one still until all the volatile salts are expelled, after which it is drawn into another, where milk of lime is added. Then heat is again applied until the fixed salts are decomposed and the ammonia is driven off. The ammonia and volatile salts are condensed in a chamber containing sulphuric or hydrochloric acid. Some hydrogen sulphide and other foul-smelling gases pass out of the absorption vessel and are led into the chimney or otherwise disposed of.

The only liquid waste from ammonia works is the lime sludge from the exhausted milk of lime. It should be sedimented and the solid portion sold as fertilizer, for which it is well suited on account of the traces of ammonia salts that it contains. The supernatant liquid on the sedimentation beds contains lime salts in solution and is usually disposed of by running it into a convenient stream.

WOOL SCOURING.

Before raw wool can be manufactured it must be freed from the impurities which constitute 30 to 80 per cent. of its total weight. They consist of the "yolk" and suint, which exude from the body of

e animal with the perspiration, and the dirt and dung mechan-
lly mixed with them. The yolk is made up of fatty or waxlike
dies which are not easily saponified with alkali, but which can be
ulsified with soap solutions and thus easily removed from the
er. The suint consists mainly of potassium salts of acetic and
ty acids, together with sulphates, chlorides, phosphates, and
rogenous bodies. All these substances are generally removed
washing the raw wool in especially designed machines. It was
merly a common practice to wash wool in stale urine, which was
ective because of the ammonium carbonate it contained. This
s been largely replaced by ammonia, soaps, etc. The wool is first
mersed in a soap solution which contains more or less impurities
m its previous use. From this machine it passes into a second
ntaining cleaner water and finally into a third which contains clear
ater or fresh soap liquor.

The wool is then taken out and dried, while the foul-smelling,
rty-brown liquor from the first machine is sometimes drawn off,
aporated, and calcined to recover the potassium salts, which
nount to 1 to 8 per cent of weight. In some countries the liquor
which the wool is washed is treated to recover the wool grease.
o do this the liquor from the third tank is settled to remove the
arse dirt, and then sulphuric acid is added to decompose the salts
d set free the fatty acids, which rise to the surface and carry the
ool grease with them. The water is drawn off from the magma,
hich is placed in canvas bags. The grease is kept in liquid condi-
on until all sediment is deposited, when it is turned into casks, in
hich it solidifies on cooling. It is used as a lubricant and in leather
ressing.

In this country the potassium salts are rarely recovered, it being
stomary to run the entire waste to the stream. Some of the
rgest mills now remove the fats by a gasoline process and after-
ards wash the wool to free it from dirt. The fats thus saved
re valuable by-products. The amount of water used in scouring
ool is usually 100 gallons to the pound, though in some works it
ises to 200 gallons. In a modern process of washing now coming
nto use the amount of water is reduced to 50 gallons. The liquid
esulting from scouring wool is large in volume and rich in organic
natter and in mineral matter in suspension and solution, and is not
eadily acted on by the agents of decomposition, putrefaction, and
itrification, so it is a most undesirable addition to the waters of a
tream. It is well to distinguish between the scouring liquor proper,
hich is small in volume and contains most of the impurities, and the
inse water, which is of great volume and is relatively clean. The
lassachusetts State board of health has found that wool scourings

can be purified by sand filtration, after being mixed with considerable quantities of city sewage. So far as Potomac River is concerned, however, this is not important, for city sewage in many places is not to be had.

WASHING WOOLEN CLOTH.

In the process of washing woolen cloth large quantities of water are used, and the water is grossly polluted thereby, for it becomes charged with organic matter. When the rinse from the finished goods is discharged into streams, it adds considerably to the putrescible material they contain and is therefore exceedingly undesirable.

Waste from sheddy mills consists of dirt and organic matter washed from the rags and stock. Large quantities of acid are often used and the wastes are decidedly deleterious in their effect.

DYEING.

General discussion.—The art of dyeing consists of imparting to various substances, mostly fabrics, a color of considerable permanence. Dyes are distinguished from pigments by their solubility in water, and a pure supply of that element is a necessity to the trade. The solution of the colors requires care, those derived from coal tar being particularly prone to spot and streak the goods, if this part of the process is carelessly performed. The dyeing is done in iron, wooden, or stone vessels, whose shape and capacity are adapted to the amount and quantity of goods handled. Some dyes require a high temperature, while others are injured by much heat. In any case, direct heating is always avoided, it having been found best to heat the vats by steam coils.

The phenomena of dyeing are explained by the mechanical and the chemical theories. The former assumes a mechanical absorption of the coloring matter into the pores of the fiber, while the latter regards the process as a chemical combination between the dye and some or all of the constituents of the fiber. The chemical theory seems the better adapted to animal fibers, but the mechanical theory is perhaps more applicable to vegetable fibers.

Thorp groups dyes into five classes, according to the method of their application—(1) direct dyes, which yield full colors with the use of a mordant; (2) basic dyes, which form insoluble tannates and require a mordant on vegetable fibers, but which dye animal fibers without a mordant; (3) acid dyes, which do not require a mordant on animal fibers, but which have only a limited use on vegetable fibers; (4) mordant dyes, which require a mordant on both animal and vegetable fibers; and (5) special dyes, which can be applied to the fiber only by special processes.

The trade distinguishes between substantive and adjective dyeing. n substantive dyeing the colors are applied to all fibers without a nordant, but "assistants," such as Glauber's salt, sodium phosphate, orax, soda, and soap are used with them to insure an even disposition f the color, thus avoiding streaky results. The assistants do not ombine with the color. As direct dyes are very soluble, the goods re likely to bleed when washed, but silks take them very well, giving rilliant shades and fast colors. A little acetic acid makes them fast nilling. Adjective dyeing requires the use of a mordant. Mordant- ng is of prime importance, and has for its object the precipitation on he fiber of some substance which has an affinity for and which will ffect a more or less complete fixing of the coloring matter used for lyeing. The nature of the mordant depends on the character of the iber, the kind of dye, and the effect sought. Wool is usually mor- lanted by boiling it in a solution of a metallic salt in the presence of ome acid; bichromate of potassium and sulphuric acid are often used. ilk can be mordanted in this way, but it is usually done at lower tem- eratures. Cotton has little affinity for coloring matters and has to e specially prepared. It has an affinity for tannic acid and so is mmonly steeped in a solution of sumac or catechu, after which it is shed and worked in a bath of some soluble metallic salt. An insol- le compound results which then has the property of uniting with the e. It is not always necessary to treat cotton with tannin, for an mersion in the mordant followed by oxidation or ageing is some- es sufficient. The operations of dyeing are multifarious, and it uld be out of place to detail them here. Only the enumeration of ne of the chief mordants will be attempted, with the description a few common processes, in order to give an idea of some of the stances that may be met in dye-house effluents. The mordants s both mineral and organic. They are as follows:

neral mordants:	*Mineral mordants*—Continued.
Aluminum acetate.	Copper nitrate.
Aluminum sulpho-acetate.	Tartar emetic.
Ferrous sulphate.	Stannous chloride.
Ferrous acetate.	Stannous nitrate.
Nitrates of iron.	*Vegetable mordants:*
Nitro-sulphates of iron.	Tannic acid.
Potassium bichromate.	Sumac.
Copper sulphate.	Catechu.

As assistants the common mineral acids are used, also acetic, oxalic, rtaric, and citric acids.

Cotton dyeing.—Indigo requires no mordant and is always applied ld. A common method is to make a mixture in definite proportions water, lime, copperas, and indigo, and apply it in a series of vats. nc powder often replaces the copperas.

Methylene blue is used to produce indigo shades. The cotton is mordanted with sumac at 160° F., given several turns, and allowed to steep for ten hours, after which it is wrung out and worked for twenty minutes in a 2½ per cent solution of tartar emetic. Then it is washed and dyed in a bath prepared with 3 per cent acetic acid at 75° F., the temperature being gradually raised to 160° F.

Aniline black is a dye of unknown constitution, and the color is produced directly on cotton by means of aniline oil in the presence of oxidizing agents. Two methods of procedure are used—the warm and the cold. In the warm method 75 parts of water, 32 of hydrochloric acid, 16 of potassium bichromate, and 8 of aniline oil are taken. The acid and aniline are each diluted with water and carefully mixed. The solution thus obtained is then added to the main volume of the water. The potassium bichromate is previously dissolved and added after the aniline. The cotton is immersed and worked for three-fourths of an hour in the cold, after which the temperature is gradually run up to 140° or 150° F. In the cold method 18 parts of hydrochloric acid, 8 to 10 of aniline oil, 20 of sulphuric acid at 66° B., 14 to 20 of potassium bichromate, and 10 of copperas are compounded as in the warm process, except that much less water is used. The goods are worked in one-half of the material for an hour or so, after which the rest is added and the operation continued for about one and one-half hours longer, when the goods are washed and boiled in a soap solution. In both processes the cotton is subjected to further oxidation with potassium bichromate, copperas, and sulphuric acid, which tends to prevent greening. Chlorate of soda is frequently used as an oxidizing agent in the dye bath, in which case the replacing of the potassium bichromate with vanadium chloride or vanadate of ammonium has been recommended.

Linen dyeing.—The uses to which linen is commonly put make it necessary that the colors it is dyed be fast. Accordingly, alizarin and indigo are generally used.

Wool dyeing.—Indigo is easily applied and extensively used to produce light and dark shades on wool by simply boiling the goods in a bath of the dye, sulphuric acid, and sodium sulphate. Loose wool is dyed in the so-called fermentation vat by keeping the wool below the surface of the liquid and working it with long rakes. After a sufficient time it is taken out and put in cord bags or upon rope screens and drained and oxidized, being then dipped into a dilute acid to remove the soluble impurities. Finally it is washed and dried.

Logwood is the real base of the blacks on wool, and is used with potassium bichromate as a mordant. As a rule the coal-tar colors are applied to wool without special treatment at boiling temperatures in a bath of 10 per cent sodium sulphate and 2 to 4 per cent of sulphuric *acid.*

Silk dyeing.—Silk has a great affinity to coal-tar colors, and can be yed without a mordant, though soap is commonly used to prevent potting and streaking. Heavily weighted goods are obtained by dip- ing them in an iron solution and then in liquids containing tannin, process that is often repeated several times.

Besides the dyes mentioned in the above processes the following are n common use: Fuchsine, safranine, methyl-violet, and methyl- reen.

Résumé.—The amount of organic matter contained in dye wastes is s a rule small, so that apparently they hurt the streams chiefly by liscoloring the water. In places this may be a serious nuisance, while elsewhere it may be a trifling matter. The extent of the injury s determined by the use to which the water that receives these dyes is put. In some processes of dyeing much organic matter is washed from the cloth, and then the pollution assumes a new character and becomes important.

MANUFACTURE OF WHISKY.

The first step in whisky manufacture is the making of the mash, which is done by mixing in the mash tub raw and malted grains, the former largely predominating, with water at 150° F., and agitating the mixture. The first malting requires about fourteen hours. Successive additions of water at 190°–200° maintains the temperature, the object being to convert all of the starch into maltose, which is directly fermentable by the action of the yeast, and to accomplish this the mashing must be done at a temperature of about 146°, for above it maltose production begins to decrease. By keeping within this limit of temperature the diastase from the small admixture of malt will not only greatly change the starch, but will bring about a hydration of the residual dextrine, converting it into maltose. When the wort has attained its maximum density, as found by the saccharimeter, it is drained off and a quantity of water at 190° F. is run upon the residue in the mash tub and allowed to infuse with it for one or two hours. The second wort is then added to the first. A third weak wort is often obtained and used to infuse new lots of grain. It is stated that in this direct mashing 10 per cent of the starch escapes decomposition, even though the grain may be finely ground. Hence a little preliminary warming with the water, to which has been added a little ground malt, followed by heating with water under a pressure of several atmospheres, often precedes the addition of the main quantity of malt, which is to complete the conversion of the starch and dextrine into maltose. Reduction of the loss by 5 to 10 per cent is reported by this method.

The second step in the manufacture of whisky is the fermentation of the wort. This is done by adding to the wort, which is always cooled before beginning the process, yeast (usually fresh brewer's or compressed

yeast) that has previously been softened in water. For 100 liters of grain, 8 to 10 liters of liquid yeast or 1½ kilograms of compressed yeast are used, and the best results are obtained when the temperature through fermentation rises to 94° F. Three stages of fermentation are recognized—a preliminary fermentation, during which the yeast cells grow without producing much alcohol; a main fermentation, during which the maltose is fermented; and an after fermentation, during which the dextrine is largely changed into maltose, which in turn is changed into alcohol. The time of fermentation varies from three to nine days, and the process is carried on until the density of the liquor as determined by the saccharimeter ceases to lessen.

The third step in the manufacture is the distillation of the fermented wort, which is done in stills varying from great simplicity to extreme complexity in construction.

The refining of spirits consists of the redistillation of the "low wines," as the product of the first distillation is known. The low wines have a specific gravity of 0.975, and the first product of the redistillation is a milky-white spirit abounding in oil. This is followed by a clear spirit that is caught separately, and the remaining weak spirit, known as "faints," is mixed with the low wines for another distillation.

After distillation the whisky is put in barrels, the inside of which has been charred. This is done to give the well-known amber color to the whisky and more particularly to assist in its aging, for the charred wood brings about a very complete oxidation of certain constituents of raw whisky, thereby imparting a delicate bouquet to it, and also relieves it of the injurious constituents. The barreled liquor is stored under bond for various periods and then is marketed.

The waste in the manufacture of whisky is the exhausted mash and residue from the stills. In many cases it is disposed of by feeding it to hogs and cattle. These animals are often herded under the most disgusting conditions, and the nuisance they create is almost greater than that which would result from turning this highly putrescible waste into a small water course. Sometimes the animals raised on the waste are disposed of to packers at favorable prices, and as often they are sold at a loss, so that from both a sanitary and a financial standpoint this method of disposal may be considered a failure.

The exhausted mash is a valuable food material when properly dried, and many works are recovering it and placing it on the market as a cattle food. The large volume of liquor treated makes the process an expensive one, and the profits are not always sure. A profitable method of disposing of this waste has been devised, and the reader is referred to Water-Supply and Irrigation Paper No. 179 for information concerning it.

POLLUTION IN NORTH BRANCH OF POTOMAC RIVER BASIN.

GENERAL DESCRIPTION.

North Branch of Potomac River rises at the Fairfax Stone, the extreme southwestern point of Maryland, at the eastern edge of the high plateau which divides the waters of Potomac and Blackwater rivers. The stream is the boundary line between Maryland on the north and West Virginia on the south. From its source to the towns of Piedmont, W. Va., and Westernport, Md., the river flows in a general northeasterly direction in the narrow valley it has carved for itself between Backbone Mountain, Maryland, and New Creek Mountain, West Virginia. The course of the river is tortuous and its current is swift. It has high steep banks, and the bed is filled with stones and bowlders. The channel lies nearer Backbone than New Creek Mountain, with the result that the northern or Maryland streams, with the single exception of Savage River, which has cut its way across the northern valley wall, are shorter than those on the West Virginia side. Both the northern and southern tributaries are torrential in character, being typical bright, tumbling mountain brooks. The West Virginia feeders are most important, the largest of them taking on the dignity of rivers, while most of the others are locally known as creeks, in contradistinction to the little runs that enter from Maryland. Both sets of streams have precipitous, quick-spilling watersheds; consequently in winter and spring the river and its tributaries are high and even impassible; in summer the feeders shrink and become relatively less important, and the main stream dwindles away to a thread which winds its hurried way through the stony bed. This region is sparsely settled, but mining and lumbering, the chief industries, have concentrated the population in about twenty hamlets, situated on the railroad, which closely follows the river as it winds in and out among the mountains.

NORTH BRANCH OF POTOMAC RIVER FROM WILSONIA TO GEORGES CREEK.

Wilsonia, W. Va., was formerly the westernmost of these settlements and had a sawmill which supported a small population; now it is abandoned, and Henry, W. Va., the station next below it, is the first important place in the valley. A coal mine here discharges a considerable amount of mine water into a little stream to the west of Elk Run. This is the first important pollution which North Branch receives, and the amount is large as compared to the total volume of the river at this point. The houses set well back from the river and such pollution as is received from them is indirect.

At Dobbin, W. Va., 2 miles below Henry, a dam is built across the river to furnish power for a sawmill, which is the life of the settlement. As the company uses the sawdust for fuel, it is disposed of

without injury to the river. The houses of the operatives are on both sides of the river and most of them are at some distance from it, consequently only a few of the privies pollute the river directly. A primitive water supply is provided, the source being several springs in the neighborhood. The water is piped through the main streets on the southern side of the river only.

At Bayard, W. Va., 4 miles below Dobbin, is a tannery of the American Hide and Leather Company, employing 50 hands. The waste, which consists of leakage from the bark-liquor vats and water from the boiled fleshings, together with a little lime water, enters North Branch a short distance below Buffalo Creek. At the time of the last inspection lime sludge was piled dangerously near the edge of the river bank. At no time during these inspections have any large amounts of waste liquors been observed discharging from the tannery into the river, but the fact that the bed of the stream is stained a deep brown color would indicate either that such has been the case in former times or that it occurs now at infrequent intervals. It is said that recently, when the tops of the bark-liquor vats were shortened 18 inches, a considerable pollution took place. There is no public water supply in Bayard, and the tannery takes its water from Buffalo Creek, which flows through the town and is somewhat polluted with mine water. The water from this stream is said to be less damaging to boilers than that of North Branch at this point. The pollution from privies in Bayard is mostly indirect, but there are a few dangerously near Buffalo Creek.

At Gormania, W. Va., 2 miles below Bayard, the A. G. Hoffman & Sons Company maintains a tannery, with 75 employees. The only wastes that enter the river directly are the weak lime liquor and that from the scouring machines. The company has built a settling pool at the edge of the stream near the factory and into it drain the heavy lime liquor, sewage from the employees' houses, and the small quantity of bark liquor that is wasted. The liquors from the pool seep slowly through the earth into North Branch, and as occasion requires the sludge at the bottom is removed to farms to be used as a fertilizer. This arrangement is a great improvement on the common practice of turning all tannery wastes directly into the river. The appearance of the river above the tannery is clear and it has some color, but more is acquired as it flows by the Hoffman tannery. As the current is somewhat slackened by a bend in the stream below the tannery the river has a tendency to deposit such material as it has in suspension. The water supply of the town consists of private cisterns, wells, and springs. Some of the privies in the town are too near the river and all of them furnish indirect pollution. On the whole, however, Gormania is an unusually clean town for this section of the country.

Stoyer, Md., is the next town downstream. It has no public water

supply and the use of privies is universal. A coal mine on the heights above the town discharges its mine water into a run which enters North Branch at this point.

Wallman, Md., owes its existence to a sawmill which is polluting the river with sawdust. To escape the Maryland authorities it dumps the sawdust within 10 feet of the West Virginia shore, and by this subterfuge works continuous injury to the stream without molestation.

Opposite Hubbard, W. Va., is a coal mine, and a short distance above a sawmill, with a huge pile of sawdust not far from the river.

At Harrison, W. Va., Abram Creek empties its waters, polluted by mine waste, into North Branch. On the Maryland side of the river, somewhat below the town, is Wolfden Run, which is likewise polluted by mine water. Below this run, at the edge of the river, are 23 privies, besides those belonging to the houses at intervals all the way to Blaine.

Blaine is an unincorporated town situated on both the Maryland and West Virginia banks, 1 mile below Harrison. Here a woolen mill which employs 10 men turns into the river spent dyes and rinse water from the finished goods to the amount of 750 gallons a day, besides the sewage of its employees. The water supply at Blaine is from private wells and cisterns. The use of latrines is universal and some of them pollute the river and the race which supplies power to the woolen mill. Others are located upon low ground in the center of the town and are scoured out by the river in times of high freshets. The privies are not cleaned, but are moved to new trenches when it becomes necessary to fill the old vaults. Thus the indirect pollution of the river is considerable.

Three Fork Run enters North Branch at Chaffee, W. Va., 4 miles below Blaine. This stream carries its quota of mine water and is likely to become more polluted in the future than it is now, because of the probable extension of mining in its valley.

At Shaw, W. Va., 4 miles farther downstream, the river receives Deep Run, which is heavily polluted with mine water and with the wastes of Atlantic and Elk Garden, two mining towns high up among the hills far back from North Branch. Elk Garden is the more important of the two, having, in fact, a considerable population. Its water supply is from private wells and cisterns, and it has no sewerage, the use of privies being general. When these are cleaned, the soil is removed to the commons on a tributary of Deep Run and buried. Elk Garden has no sewers, but there is one drain for surface water only, which reaches North Branch by way of Deep Run.

Savage River, whose watershed supports no mines and is given over to lumbering, joins North Branch near Bloomington. As its drainage area is practically uninhabited, the water is relatively pure and, being

of nearly equal volume to that of North Branch at this point, serves greatly to improve its character by diluting the impurities.[a]

Between Bloomington and West Virginia Central Junction, North Branch receives a considerable amount of mine water. The town of West Virginia Central Junction contributes its share of indirect pollution. The river passes over a dam here and with its fall changes its environment and character. Up to this point it is a turbulent mountain stream to whose immediate banks the population is confined. Back from the river the Maryland watershed is uninhabited save for a few isolated farm houses here and there, and the population supported on the upland drained by its West Virginia tributaries is scattered, except that in some places about the country stores a few homes are clustered. From this point on, North Branch becomes less wild and on its banks appear populous towns with varied industries and in some cases sewerage systems. The influences of nature are less manifest and the artificial conditions imposed by man are everywhere visible.

A little below the dam the town of Luke, Md., has been built up by the West Virginia Pulp and Paper Company. Seven hundred men are employed in the factory, and the sewage which they create is turned straight into North Branch, as is also the waste from the factory, which is the largest industrial plant in the whole Potomac basin. Soda pulp, mechanical wood pulp, and paper are made here, and enormous quantities of alum, soda bleach, and lime are used, besides kaolin, glue, size, and ultramarine blue. The discharge of the waste chemicals and the shreds of wood fiber radically alter the character of the river at this point.

From Luke it is but a short distance to Westernport, Md., and Piedmont, W. Va., two towns on opposite sides of the river, which have identical interests and form one community. Piedmont has a sewerage system and pollutes North Branch both directly and indirectly.[b] The town owns its water supply, which, by arrangement with the West Virginia Pulp and Paper Company, is pumped from Savage River. Though the water undergoes no process of purification, it has so far been used with good results, being only slightly polluted, owing to the almost entire absence of population on the watershed from whence it is derived. Westernport for the last three years has bought its water from Piedmont. Its use is general in the town, for the wells along Georges Creek have been destroyed by infiltrating waters from the creek, so that the only wells in use are those in the western part of town, which is higher than the other parts. The town has two sewers. One of them has 50 connections, runs parallel with the main street, and is 600 feet long and 30 inches in diameter. The other has 500

[a] *The results of measurements of Savage River at Bloomington are given on pp. 43–46.*

[b] *The results of measurements of North Branch of Potomac River at Piedmont are given on pp. 46–54.*

nnections, is partly open, and is 500 feet long and 36 inches in ameter. Both discharge into Georges Creek near its mouth. Besides ese a few private sewers empty into the creek and North Branch.

GEORGES CREEK.[a]

Georges Creek has its source on Big Savage Mountain, and drains ie heart of the soft-coal region of Maryland. At its very head at ew Shaft a large stream of mine water is constantly running, and ience all along its course accessions of mine water are received at ort intervals, so that by the time Westernport is reached the waters re surcharged with mine drainage, and are lethal instead of life giving i character. They destroy all vegetable and animal life in the chan-el, and stain the rocks on which they flow yellow with a deposit of on hydrate.

At the head of the creek on a high peak of Big Savage Mountain is ie city of Frostburg. It has a good public water supply from springs n the mountain, and the Frostburg Water Company furnishes an uxiliary supply derived from a well and springs. The city for the ast three years has had about 15 cases of typhoid fever each year. ome of the cases are of outside origin. There is no sewerage system i Frostburg nor is there need of any, for the coal mines beneath the own drain all the cesspools and care for some of the surface water as ell.

Below Frostburg are Borden Shaft, Ocean, and Midland, all mining ommunities in which crude sanitary conditions exist.

Lonaconing, about midway between Frostburg and Westernport, s also a mining town. It has developed a public water supply on ackson Run for a reservoir fed by two mountain streams upon whose atersheds but two or three families live. The water is at present deliv-ered to 523 families, but the available supply is 5,000,000 gallons a day. he fact that but nine cases of typhoid appeared in the city during leven months of 1904 points to the comparative purity of the water. he death rate in the town is about 10 per thousand and is said to be ugmented by the high birth rate, for the local statistics seem to show iat a large number of children die before reaching 5 years of age. here are some sewers which serve a few houses, stores, and hotels id which empty into Georges Creek, as do the many privies that rectly overhang it. Besides these, four shambles exist, one of hich is far from the town, and buries its offal. The three others are the middle of the town and are used by six butchers, who throw uch of the offal into the creek, though some of it is fed to hogs. here is one steam laundry which drains into Koontz Run.

[a] The results of stream measurements of Georges Creek at Westernport are given on pp. 55–57.

NORTH BRANCH OF POTOMAC RIVER FROM GEORGES CREEK TO WILLS CREEK.

At Westernport North Branch turns and flows in a southeasterly direction across the foothills of New Creek Mountain until it reaches Keyser. At this place the most obvious contamination is from the mill of the Patchett Worsted Company, which scours 1,800 pounds of wool a day and uses 100 pounds of aniline dyes a week. The wastes are turned directly into the river. This company has had some trouble with its water supply. The Potomac water, it is claimed, makes the wool which is washed in it harsh, while the waters of New Creek stain the wool badly.

On New Creek, 6 miles above Keyser, a plant of the United States Leather Company is located. Above this plant the water is colorless, or nearly so, while below the place where the tannery discharges liquors the stream becomes red or almost black. Though the color is reduced in the course of flow to the river, the water is still tawny at the creek's mouth. The tannery employs 99 men. In the summer of 1904 there was an outbreak of typhoid among them, due, it is thought, to contaminated springs and wells in the neighborhood. New Creek is polluted by sewage also, for while the use of privies is common in Keyser a part of the town is pretty thoroughly sewered, and the sewer empties into the creek, as does that of the Baltimore and Ohio Railroad shop, with 300 employees. The latter connection is indirect, reaching the creek through Longs Gut. Typhoid fever is said to be rare in Keyser, by reason of the purity of the water supply in general use. The source is a mountain spring 4 miles east of the town. The reservoir has a capacity of 6,750,000 gallons and affords a pressure of 160 pounds per square inch in the lowest part of the town.

WILLS CREEK AND CUMBERLAND.[a]

At Keyser the Potomac resumes its northeasterly course and flows between Dans Mountain on the north and Knobly Mountain on the south to Cumberland, where it receives the waters of Wills Creek. The drainage area of this creek must be carefully studied in order to understand sanitary conditions in Cumberland.

Wills Creek rises on the western slope of Savage Mountain, Pennsylvania, and runs northwestward to Mance, where it turns and flows eastward to Hyndman. The population on its entire watershed above Hyndman is not more than 1,000, and not many of the small villages need especial notice.

Foley is a railroad station, with a few houses huddled about it. Most of these are provided with privies that pollute the creek, which runs on to Fairhope, where there is a brick factory, and where the stream is further contaminated by overhanging latrines. Identical

[a] The results of measurements of Wills Creek and North Branch of Potomac River at Cumberland are given on pp. 58–64.

ditions exist at Williams, the next town below, and at Hoblitzell, nall agricultural community, a few more houses add their filth to water course.

Hyndman is the largest town on Wills Creek. Its public water sup- comes from a spring on the west side of Wills Mountain, 1½ miles n town, and its purity is evidenced by the fact that there is rarely typhoid fever in the place. There is one sewer, about a quarter of ile in length, which takes slops from the houses on the line and soil n a few of them and from the bank and hotels. The rest of the abitants use privy vaults, which seem to be well cared for by the l board of health. The tannery of the Elk Tanning Company, ch employs 55 men and makes oak-tanned sole leather, on the tern bank of Wills Creek, when first visited poured all its wastes ctly into the creek. Since then conditions have been bettered, the company has constructed at the edge of the stream near the t a settling pool with a capacity of 5,500 cubic feet, and all wastes turned into it. At the time it was inspected it was full and over- ing a little, and it was observed that a sluice with a gate had been vided by which direct communication with the creek could be blished in case the capacity of the pool was overtaxed. In spite hese defects the new arrangement is commendable, and has done a t deal toward clearing up the waters of the stream. A privy ch is used by the employees overhangs the creek and a water et in the office of the company is also connected with it. The acity of the plant is 105 hides a day, and the total wastes are esti- ed at 2,000 gallons a day.

ome distance below Hyndman is Ellerslie, where there is a planing and a pumping station of the Standard Oil Company. At Cor- nville Jennings Run joins the creek. This stream heads at Frost- g, and both near that town and at other places in its narrow valley ives large quantities of mine water. At Mount Savage it is ed by Mount Savage Run, which is polluted by many overhanging ies, and upstream by the acid waters of a fire-clay mine. Mount age is located on the steep slopes of high hills, so that the run-off ugh the town is very quick, and in times of heavy rains a great of the refuse of the town is washed into Jennings Run or its utary, Mount Savage Run. At Barrelville a small tributary rs Jennings Run from Wellersburg, and that too is contaminated nine water from the coal mines which are being opened up in its ey; but from Barrelville to its mouth the run is befouled but little e.

elow Corriganville there is no notable pollution until Braddock is reached. This stream heads at Eckhart Mines, a thriving ing town that is supplied with water by the Frostburg Water pany. Privies and domestic wastes defile the run, but it is free

from mine water, owing to the fact that the waters of the mines beneath the town are pumped into Georges Creek near Borden Shaft. The completion near Clarysville of a tunnel, now far advanced in construction, 11,000 feet long and 7 by 8 feet in cross section, will divert the drainage of the Eckhart and Hoffman mines from Georges Creek to Braddock Run, into which it was formerly pumped. The effects of the consummation of this project will be far-reaching. Braddock Run, whose waters are now comparatively soft and suitable for boiler purposes, will be converted into a stream with the characteristics of Georges Creek at the present time, while the water of Georges Creek will become less acid and so less potent in its effect on the limy waters of North Branch at Westernport. Moreover, with the reduction of its acidity the Georges Creek water is likely to become less noxious to bacteria, so that the sanitary conditions which prevail along the creek will be vastly more important than they now are to the towns below it, notably to the city of Cumberland, whose waterworks intake is at Ridgely, on North Branch, one-half mile above Wills Creek. The Cumberland water now receives the benefit of the clarification and germicidal action which the united waters of Georges Creek and North Branch accomplish about 30 miles above it, and should this action become less effectual it is conceivable that Cumberland might find its water supply less pure than it is now. The acid waters of Braddock Run after this change is made effective will increase the acidity of Wills Creek, and that in turn will work its effect below. At present Braddock Run flows from Eckhart Mines to Allegany Grove, a camping and picnic resort where many large privies pollute it badly. Somewhat below Allegany Grove is the plant of the James Clark Distilling Company, whose wastes, consisting of slops from the distilled grains, are conducted through a 10-inch terra-cotta pipe along the sides of the run to the Narrows, where they are discharged into Wills Creek. The concern mashes 300 bushels of grain a day, but the amount of waste disgorged into Wills Creek is problematical, as a farmer below the distillery taps the pipe line and withdraws what he needs for his cattle, while another one hauls away enough to supply a herd of forty. The fact that the distillery is closed down in summer is undoubtedly of benefit, for the waste, which is putrescible, is thus usually discharged only in times of comparatively high water, which tends to dilute it. Moreover, at summer temperatures a local nuisance would be created about the Narrows by rapid decomposition of the distillery slops, whereas under present conditions, at the lower temperatures of autumn and winter, decomposition is more gradual, as it takes place at a comparatively slow rate and over a considerable distance.

Below the Narrows of Wills Creek is a tannery of the United States Leather Company, where the course of the stream varies with its

In times of low water practically the entire stream is diverted
e dam at the tannery into the Beal mill race, which flows through
ost populous part of Cumberland into the Chesapeake and Ohio
. When the creek is high, so much of its waters as do not go
gh the race continue over the dam and flow through the busi-
ection of Cumberland to the head of the Chesapeake and Ohio
, into which, when the gates are open, some of the water goes,
the rest joins North Branch. At a point a little below the
ence Dam No. 7 has been built. Its purpose, like that of the
dams on the Potomac, is to hold back the waters of the river
ake them available for feeding the canal; its effect is to check
rrent of Wills Creek and to create slack water for 3 miles up
Branch. It can be easily understood that in times of drought,
no water passes over the dam at the tannery on Wills Creek
one over Dam No. 7, there is formed a bow-shaped pool of
cally stagnant water, one arm of which extends from the Wills
dam to North Branch and the other from Dam No. 7 up North
h for 3 miles. The river arm is but little polluted, while the
arm throughout its length of a mile through the center of Cum-
d is very much so. Into it slaughter barns, privies, steam
ries, breweries, and some of the sewers of the city discharge,
cing a thoroughly regrettable condition of affairs. In time of
water this corruption is carried into the canal or river, but
ever there is a drought it lies festering in the midst of the city.
nberland is the largest city on the Potomac watershed above
ington. It is a vigorous, growing place, but its rapid increase in
ation has outstripped its development in sanitary matters. The
of the city is not free from contamination. As private wells
mmonly polluted, most of them have been closed up. Cisterns
ed to some extent, but the city supply is generally relied on by
itizens. It is pumped directly out of North Branch opposite
ly, 1 mile above Wills Creek, and is consumed without purifica-
f any kind. This would probably be more disastrous than it
s were it not for the beneficial purification which, as explained
here, takes place about 30 miles above the city. There is no
n of sewage purification, though there is a sewerage system
serves about 75 per cent of the city. Soil, slops, and some
e drainage are taken by the sewers, though about 95 per cent
system carries no storm water, as most of the surface drainage
directly to the race, canal, creek, and river. Six of the city
s discharge into the race; two of these are 36 inches in diame-
ne 12 inches, one 10, one 8, and one 6. Besides these the race
es the droppings from many overhanging privies and is polluted
any private sewers. The dye works of Thomas Footer & Son
arge wastes consisting of rinse water and spent dyes, estimated

at 10,000 gallons a day, into the race, together with the sewage of its 310 employees. Moreover, the race is somewhat obstructed by ashes which are thrown into it. Besides the sewers discharging into the race, the following empty into the river: One 24-inch sewer, whose full capacity is probably never required, entering at Valley street; one 6-inch private sewer for sewage only, entering at a point about opposite the Town Hall; one 12-inch city sewer, and the 8 or 12 inch sewer owned by Allegany County. In South Cumberland a sewer empties into a brook that flows into the Chesapeake and Ohio Canal near the Queen City glass factory. In winter, when the canal is drained off, the stream and sewage flow over the canal banks directly into North Branch. About 5 per cent of the houses in South Cumberland are connected to this sewer.

Many people along Wills Creek find it to their advantage to sewer directly into it. Above the Market Street Bridge the United States Leather Company, which employs 100 men, discharges its tannery wastes, amounting to 10,000 gallons in twenty-four hours, together with the sewage of its employees, into the creek. Below this tannery the Cumberland Brewing Company, employing 50 men, empties the washings from its barrels and sewage from its employees. At the Market Street Bridge, on the west bank, the German Brewing Company pours out the washings from its barrels, amounting to 1,500 gallons per day, together with the sewage of its 35 employees. On the opposite bank a gas company lets some of its waste liquors escape. From this point down, on the eastern side of Wills Creek, there is a succession of overhanging privies, interspersed by the sewers of two steam laundries and by a few slaughterhouses, whose floors drain the blood of the animals and with it a small amount of offal into the creek (Pl. VIII, A).

Throughout the southwest part of that section of Cumberland lying west of Wills Creek flows a small run that is undoubtedly the recipient of much promiscuous refuse, which it empties into North Branch about one-fourth of a mile below the waterworks intake at Ridgeley. Whether this imperils the city water supply or not can not be stated, but the possibility of its doing so should be borne in mind.

The Chesapeake and Ohio Canal receives most of the irregular pollution of South Cumberland. The Baltimore and Ohio Railroad shops, employing 600 men, sewer into it, and so does the N. & G. Taylor Company, a concern which employs 300 men and which makes steel and rolls it for manufacture into tin plate. In the process of manufacture large quantities of sulphate of iron are used, and this when pretty well exhausted finds its way into the canal.

There are many other industries in Cumberland, but none of them have liquid wastes. That other manufacturers will come to the city *is more* than likely, for Cumberland is advantageously situated and

A. WILLS CREEK FROM MARKET STREET BRIDGE, CUMBERLAND, MD.

B. POLLUTION OF POTOMAC RIVER BY WASTES FROM THE MECHANICAL WOOD-PULP MILL AT HARPERS FERRY

ıs destined to enjoy much greater prosperity. This, however, be still further increased by bettering the conditions above de- ɔed. The city should adopt some method of disposing of its :es which will relieve the river of doing so, and its water supply ıld be placed above criticism.

NORTH BRANCH OF POTOMAC RIVER BELOW WILLS CREEK.

elow Cumberland North Branch enters the Greater Valley of the alachian Plateau in that part known as the Allegheny Ridges, ı the fact that mountains trending northeast and southwest cross t frequent intervals. In the valleys between these ridges flow ıy streams, and the most prominent of these will be taken up in order in which they empty into North Branch.

vitts Creek, which drains the thinly settled country between ver Ridge and Evitts Mountain, enters North Branch from the h a short distance below South Cumberland, where its water is l for boiler purposes in the Baltimore and Ohio Railroad round- se. At one time it was advocated as a source of public water ply for Cumberland, but was rejected partly because of the ralence of typhoid in its drainage area. Patterson Creek, the t important tributary, comes in from the south at Patterson ot. Burlington, with a population of 250, is the largest town in Patterson Creek Valley; its inhabitants gain their livelihood farming and logging. From Patterson Depot North Branch flows to a point 2 miles east of Greenspring and then loses its identity, ıg joined by South Branch of the Potomac to form the main am, whose conditions will be described after taking up South nch.

OLLUTION IN SOUTH BRANCH OF POTOMAC RIVER BASIN.[a]

outh Branch of the Potomac rises in Highland County, Va., at htown, on the divide separating the headwaters of James and omac rivers. The stream flows northeastward to a point 6 miles t of Petersburg, W. Va., where it receives North Fork of South nch, which is formed at the north end of Middle Mountain by the fluence of Laurel Fork with Straight Fork and flows northeast- d to its junction with South Branch. The stream continues in a theasterly direction to Moorefield, where it receives the waters of ɔrefield River, a stream that flows in a northeasterly course from ɔource on Shaw Ridge north of Palo Alto, Highland County, Va., r the head of Cow Pasture River, a tributary of the James. The re country drained by South Branch of the Potomac is very ged. Several of the mountains rise to the height of 3,000 feet

[a] ıe results of stream measurements on South Branch of Potomac River at Springfield, W. Va., ven on pp. 66-77.

and there are many less lofty peaks. The watershed is much cut up by the multitude of creeks and runs that are tributary to the main stream, and these waters fall precipitously into the river from the mountains, making it rise and fall suddenly. In spring the melting of the snow produces very high water, which recedes quickly.

South Branch from its source to a point 6 miles west of Petersburg flows between North Fork and South Fork mountains, and lies between North Fork of South Branch and Moorefield River, both of which are parallel to it, all three streams flowing in a northeasterly direction. North Fork Valley has been eroded between Spruce and North Fork mountains. Its population of woodsmen and mountaineers is very sparse, so that the stream may be dismissed with the statement that it reaches South Branch almost unsullied. Moorefield River has cut its valley between Shenandoah and South Fork mountains; the region is unsettled and, like North Fork, the stream is but little polluted. The only source of contamination is a tanning-extract factory located in Brandywine, Pendleton County, W. Va., a place where it is said there has been much typhoid. When this plant was started the stream was discolored greatly by the leakage from the vats where the chestnut-oak wood was steeped. At the present time this leakage is insignificant and such coloring matter as enters the stream comes from the condenser water, which absorbs some of the abstract in the process of manufacture.

South Branch itself in its upmost reaches is polluted only by the wastes at Monterey, Highland County, Va., and by those of a few scattered settlements. At Franklin, however, where the stream has attained considerable size, the pollution is important. This town has a water supply from springs on Entry Mountain, but about one-third of the people use wells. The sewage must reach the river very indirectly, for the houses are a long way from the river bank and there is no public sewerage. One or two private sewers lead from the main streets of the town to the bottoms, but most of the people use privies, and the soil removed from these, when they are cleaned, is deposited in boxes near the river, which are scoured out by occasional floods. So far as information goes typhoid is rare in Franklin, though once in a while a case comes into town from the outside. The most extensive pollution of the river here is accomplished by the Franklin Tannery Company, whose wastes amount to practically 10,000 gallons a day. The factory is located in the southwestern part of the town, and its effluents are carried 1,100 feet through a 6-inch terra-cotta cement-jointed pipe line to a settling pool 83 yards from the river. Here the solid matters sediment out, and the liquids usually filter slowly through the ground to the river. In times of high water the earth becomes saturated, causing the pool to discharge at its south end

directly into the stream, while in times of flood the entire settling basin is invaded by the river. This is considered unavoidable by the tannery company, because in its opinion the best available place has been utilized for the disposal of the waste. The company claims that this refuse, which must ultimately go into the river, is best discharged at such times, for in the huge volume of water that rushes downstream it is hardly noticed and presumably does comparatively little harm.

The country between Franklin and Petersburg is given over to grazing and farming and is very beautiful. The pollution received by the river in this interval is very small and is such as comes from scattered farmhouses and the domestic animals about them. At Upper Tract there is a country store and something of a settlement. Petersburg is a small town at which there is a tannery of the United States Leather Company that employs 30 hands. The wastes from this plant amount to 3,000 gallons daily and are discharged into Lunice Creek very near the point where it enters South Branch. At the time of inspection South Branch was in flood, so that the effects of the tannery wastes were not discernible, but it is entirely probable that in low water they discolor the stream, for there is no attempt to purify them. Petersburg has neither public water supply nor sewerage, and the only receptacles for soil are privies. The next town below Petersburg is Moorefield, which takes its water from Moorefield River, a short distance above the tannery dam on that stream. The daily consumption is 36,000 gallons. Besides this, nearly every house has its well, and these are locally supposed to furnish water of good quality. There are no sewers, but there are one or two drains for surface water. The tannery at Moorefield at the time of the inspection was owned by the Cover & Drayton Company, but has now passed into the hands of the United States Leather Company. It is situated well back from the bank of Moorefield River, about 2 miles from the center of the town. The plant has a capacity of 50 hides a day, and its wastes, which amount to 10,000 gallons a day, are carried to a settling pool near the edge of Moorefield River. This pool is believed to be large enough to take care of the tannery wastes at all times, but in case it is not the liquors will be discharged directly into the stream. Like the settling pool of the tannery at Franklin this one is flushed out by floods.

At Old Field, a short distance below Moorefield, South Branch flows between Mill Creek Mountain and South Branch Mountain in a precipitous valley locally known as the Trough, while the highway turns around the southwest end of Mill Creek Mountain and follows the valley of Mill Creek to Romney, passing on the way the settlements of Purgitsville and Moorefield Junction. The inhabitants of these places are farmers and the population is very small.

Romney is situated on a high hill well back from South Branch where it emerges from the Trough. It has a public water supply from springs, but no public sewerage. The State asylum for the deaf and blind located here has a private sewer that discharges into Big Run, and this rivulet carries the sewage into South Branch one-half mile below the town limits. From Romney to its mouth the valley of South Branch is peopled by farmers and there is no further important pollution.

The waters of this large stream are remarkably pure and should be protected from contamination. Its beautiful valley, with its rugged mountains, interesting streams, and fair intervales, so near the populous cities of the seacoast, is likely to yield a richer return as a wisely developed region of summer resorts than under exploitation by industrial interests.

POLLUTION IN POTOMAC RIVER BASIN BETWEEN MOUTH OF SOUTH BRANCH AND SHENANDOAH RIVER.

POTOMAC RIVER FROM MOUTH OF SOUTH BRANCH TO PAWPAW.[a]

The first important stream entering Potomac River below the confluence of North and South branches is Little Cacapon River, a southern tributary. A few miles below this stream is Pawpaw, W. Va., a small town at which there is a tannery that employs 140 men. The tannery wastes amount to 15,000 gallons a day. Part of them are sedimented near the river's edge, but the rest are discharged directly into the river and markedly discolor it.

From Pawpaw the river takes a meandering course between Town Hill and Sideling Hill. At the hamlet of Little Orleans Fifteenmile Creek enters from the north, and 4 miles farther downstream is the mouth of Sideling Hill Creek. The Potomac then cuts across Sideling Hill and Tonoloway Ridge, on the eastern side of which lies the village of Great Cacapon.

GREAT CACAPON RIVER.

A short distance east of Great Cacapon is the mouth of Great Cacapon River, which is formed at Forks of Capon by the junction of North River and Cacapon River.

North River rises in South Branch Mountain, Hardy County, W. Va. Two tanning-extract factories are located in this stream, one at Inkerman and the other at Rio. Cacapon River, or Lost River, as it is known above Wardensville, on account of its sinking beneath its bed for a short distance, rises in North Mountain, Hardy County, W. Va. There are two tanneries in its basin, one at Lost City and the other at Capon Bridge. Each employs 25 men and turns out 50 hides a day. The wastes are said to be sedimented before being turned into the river.

[a] Results of measurements of Potomac River at Great Cacapon are given on p. 78.

Great Cacapon River is less than 75 miles long. For a considerable stance above its mouth it is about 150 feet wide. It is made up of succession of rapids and pools. In some of the pools the water is ep, but the rapids are shallow. In ordinary stages the river is ford-le at almost any place except in the pools. The lower part of the er has a considerable fall per mile and is full of large rocks and wlders.

POTOMAC RIVER FROM GREAT CACAPON RIVER TO CONOCOCHEAGUE CREEK.

The next important tributary below the Great Cacapon is Warm ring Run, which enters the Potomac from the south at Brosius. is stream is polluted by sewage from the town of Berkeley Springs, ich is 6 miles from the Potomac and which owes its existence to ermal springs that supply the community with water and are held high esteem. The hotels and leading houses are served by a sewer ich discharges into the run about one-half mile north of the town. Opposite Brosius is Hancock, one of the oldest towns in Maryland. is a small place without factories, and as it is located well back m the river the trivial refuse that is created there must reach the eam either very indirectly or by the two runs which flow along the treme east and west ends of the town. The pollution at Hancock ay become more important in the future if the stimulus recently ceived from the advent of the Wabash Railroad is sufficient to velop steady growth. From Hancock the Potomac continues its ay eastward. From the north, a little east of Hancock, it receives reat Tonoloway Creek; from the south, a considerable distance far-ier on, Sleepy Creek; and beyond that, from the north, Licking reek, a stream which rises in Bedford County, Pa., and receives the direct pollution of McConnellsburg, a sizable country town, where ere is a tannery having a capacity of about a hide a day. A few iles below Licking Creek, Back Creek joins the river from the south. bove Dam No. 5 the Chesapeake and Ohio Canal enters the Potomac nd becomes one with it for miles, not resuming its separate course ntil it reaches Dam No. 5, 7 miles above Williamsport, Md., where onococheague Creek enters the river.

CONOCOCHEAGUE CREEK.

Conococheague Creek has intrenched itself in the eastern edge of umberland Valley and drains a well-populated, prosperous region. he stream rises in South Mountain, Adams County, Pa., and flows in westerly direction by many villages. At Scotland there is a large dustrial school, which disposes of its sewage by the Waring system, matter of importance to Chambersburg, the city next below it. he water supply of this flourishing city is pumped from Conoco-heague Creek at a point 2 miles upstream and is delivered without rification to the citizens, nearly all of whom are dependent on it,

for the well water is too hard to be used satisfactorily in boilers and is commonly so polluted that the wells have fallen into disuse. Chambersburg has no public sewerage system, probably because the seams of the much fractured limestone on which the city is built act as conduits for the sewage of the cesspools that are as a matter of course provided for every house and carry it away, presumably to the creek. There are two private 10-inch sewers, to one of which are connected three hotels and fifteen private dwellings and to the other a hotel, the trust company, and the court-house. There is also a private 8-inch sewer which is used by 25 families and another for the 300 employees of the Wolf Company. All these sewers empty into Conococheague Creek, which is further corrupted by a part of the sewage of the Wilson College for Girls, an institution having 400 students, by the washings of a creamery and of a beer-bottling establishment, by the spent lye of J. G. Gerbig & Sons' soap factory, by the residues of the Chambersburg Gas Company, and by the spent dyes of a small dyehouse which maintains its own connection to the creek. Moreover, three slaughterhouses utilize the stream for the disposal of their offal. Its tributary, Falling Spring Run, increases the pollution, for to this little stream are connected the urinals of the Cumberland Valley Railroad shops, which are used by 230 men, and the five water-closets of its main office building, where there are 50 employes. The run is also the recipient of the sewage of the 90 hands of the Chambersburg Shoe Company. The Chambersburg Woolen Company voids into it the sewage of the 95 employees, together with wastes consisting of spent dyes and rinse water from the finished goods; and, finally, a steam laundry adds its affluent. From Chambersburg Conococheague Creek runs southwestward for 15 miles to the point where it receives the waters of Back Creek, a stream on which is located Williamson, a small town, where a large dairy and butter factory pollutes the water.

Four miles below its confluence with Back Creek, Conococheague Creek is joined by Moss Bank Run. This little stream probably receives practically all of the sewage which leaks away from the cesspools in the limestone that underlies the city of Greencastle. The run at the eastern edge of the city receives the washwater and dyes of a little woolen mill and then disappears below ground, apparently to reappear on the western side of the city, from which point it flows eastward 1 mile to Conococheague Creek. Greencastle is supplied with water by the Greencastle Water Company from Eshleman and Spangler springs, 2 miles east of the city. It is a gravity supply and was put in at a cost of $30,000.

From Moss Bank Run Conococheague Creek flows southward for 5 miles, and then receives the waters of its West Branch, which rises on the divide between Cumberland and Franklin counties and flows *southward* until it reaches the main stream. The first contamination

West Branch is received a short distance above Mercersburg Junc-
on, where the waters of Trout Run come in. This stream heads in
ove Mountain a little to the west of Foltz, in Cove Gap, and passes
rough the hog yard of a small distillery. The animals are fed on the
ops, and while they doubtless dispose of most of it probably a part
capes, and with the excrement of the swine contaminates the stream.
From Mercersburg Junction, West Branch continues to a point
out 2 miles east of Mercersburg. This city has a public water sup-
y derived from Trout Run, before mentioned, at a point above
e distillery known as Buchanan's birthplace, where there is a dam
ross the run, the slackened waters being piped to an equalizing
servoir and thence to the city. The supply is probably very satis-
ry, because the waters are tapped in the Pennsylvania Forest
eserve, which insures their freedom from contamination. The
ater is used generally in the city, but is supplemented by six public
ells, which are on the main street. The sewerage system consists
f two sewers, one a 6-inch pipe 2,500 feet long, laid through the
ain street, and the other an 8-inch pipe 800 feet long, known as
e Church street sewer. Besides these, Mercersburg College, which
as 300 students, has a private sewer. All this sewage, together
ith the effluent of the tannery, is discharged into a little rivulet
own locally as Dickeys Run, heading back of the town. When
spected at the point where it crosses the main street this run was
mply a brooklet of blood owing to the discharge of a slaughterhouse
ar by. Below the slaughterhouses is located the tannery of W. D.
ryon & Sons. The capacity of the plant at present is 75 hides a
y, but it is being increased. The wastes now amount to 2,500
llons a day, and by agreement with the property owners below
e discharged only at night. The length of the run to West Branch
2 miles. Near its mouth, at the time of inspection, it did not
ow evidence of the gross pollution which it receives, though as
was inspected in daytime the tannery effluent was not a factor.
West Branch joins Conococheague Creek 10 miles below Dickeys
un, and from the confluence the creek continues without conspicu-
s pollution to Williamsport, Md., where it joins the Potomac.
is town was at one time visited by General Washington to deter-
ine its advantages as the future capital of the United States. At
esent it is a large, beautifully located village without a public
ater supply and without sewerage, though authority to construct
e former was given at the last session of the legislature. There
a little manufacturing done, but the industries do not create
uid wastes, with the single exception of the tannery of W. D. Bryon
Sons. This firm employs 250 men, and its wastes, amounting to
,000 gallons a day, are discharged into Conococheague Creek but
short distance above its mouth.

OPEQUON CREEK.

Opequon Creek rises east of Stephens City, Frederick C
Va., and flows northeastward, emptying into the Potomac R
miles east of Martinsburg, W. Va. In general its course is st
but from Middleway to Martinsburg it is somewhat mean
Although this stream is small, and through most of its cours
in a farming region in which it receives but little pollution a
mostly indirect and derived from enriched land, domestic a
and a score of scattered hamlets, yet from the sanitary standp
is important because of the nature and amount of sewage r
at three different places.

Winchester, the county seat of Frederick County, Va., is s
on Abrams Creek, 5 miles from Opequon Creek. It has a
water supply which consists of what are known as the old a
new waterworks. The old works date from colonial tim
derive water from a spring three-fourths of a mile west of the
house; the new works, installed in 1894 at a cost of $55,0
supplied from a spring three-fourths of a mile southwest of the
house and afford 2,500,000 gallons in twenty-four hours.
is no sewerage system and the use of cesspools and privy v
universal; they care for themselves by draining away throu
crevices of the limestone. Probably much of the pollutio
mately enters Town Run, which passes through the center
town and joins Abrams Creek. Besides the indirect contami
Town Run receives waste from a steam laundry and gas hou
latter makes the run foul and ill smelling. Near the gas house
Graichen's tannery discharges its effluent, made up of lime
bark liquor, and water from wool scourings, all of which a
to 200 gallons a day; the Winchester creamery contributes th
ings of its floors, vats, and cans; the Lewis Jones Knitting Co
adds spent dyes and run-down lime bleach; and the Virginia
Company discharges its waste, consisting of 1,000 gallons a
scouring liquors and spent dyes. This unsavory burden is
ered by Town Run to Abrams Creek on the southeastern ou
of Winchester. West of Winchester, nearly 3 miles above the
of Town Run, Abrams Creek receives the waste of the Ar
Strawboard Company's factory, which makes paper boar
old newspapers. The effluent is dirty water full of shreds o
and is run into a settling pool from which it flows into Abrams
The sediment is occasionally taken out of the pool by farm
use as a fertilizer. A. C. Williamson & Brothers, manufactu
woolen goods for public institutions, pour the rinse from their
factured goods and some spent dyes into the creek, after w
flows 7 miles to Opequon Creek without further industrial po
other than that delivered by Town Run, as already mentioned

Two miles below the mouth of Abrams Creek, Opequon Creek receives Lick Run, which, at Jordan Springs, is polluted from June to September by the sewage of a summer hotel and its cottages, planned to accommodate 300 guests.

Martinsburg, W. Va., is on Tuscarora Creek, 1 mile from Opequon Creek.[a] In past years the city suffered seriously from typhoid, but the citizens finally delivered themselves from the scourge by closing up the wells and abandoning the old water supply, both of which were considered to be polluted. A new and satisfactory water supply from Kilmer Spring, 1 mile west of the city, was installed in 1903, at a cost of $30,000. There is no sewerage other than four drains, aggregating 2,000 feet in length; these are for surface water only, which they discharge into a tributary of Tuscarora Creek. About 5 per cent. of the houses have water-closets, and these empty into cesspools; the rest of the people are dependent on privies. Both cesspools and privies are well looked after, owing to the city's experience with typhoid, but they undoubtedly furnish Tuscarora Creek with considerable indirect pollution. Only one privy, that of the electric-light company, was noticed to overhang the creek directly.

Tuscarora Creek is greatly polluted by industrial wastes. The first and most noticeable of these is that of the Hannis Distilling Company, amounting to 8,000 gallons in twenty-four hours. Inasmuch as it consists of slops from the mash, which is a good cattle feed, much thought has been spent by the company in devising means to separate the solid portion from the liquid in which it is suspended. By means of a somewhat elaborate system of settling and filtering, all but the finest impalpable material is saved and put on the market. The part that is discharged into the creek is finely subdivided matter in suspension in weakly acid liquor, and has defied every device of the company to recover it. Once in the stream it collects in long undulating streamers, which adhere to the banks and bottom, giving the creek an unsightly appearance. As this effluent is undoubtedly good food for algæ and bacteria, it favors their development.

A considerable distance from the Hannis distillery, at the south end of the city, the gas company discharges ammoniacal liquors into the stream. Opposite the gas works a little run enters which carries most of the manufacturing effluents received by Tuscarora Creek. The Gilbourn Knitting Machine Company's waste amounts to 10,000 gallons a day, and consists of wool scourings, spent dyes, and rinse waters from the manufactured goods. These liquors are run into a settling pool, whence they overflow into the run. The solid matter is pumped out from time to time and allowed to stand in the vicinity of the pool. The Crawford Woolen Company discharges directly into the

[a] Results of stream measurements on Opequon and Tuscarora creeks near Martinsburg are given on pp. 78–82.

run 10,000 gallons of spent dyes and 5,000 gallons of wool scourings in twenty-four hours. The Martinsburg Worsted and Cassimere Company utilizes the run for its spent-dye liquors, which amount to 5,000 gallons in twenty-four hours.

No other important contamination taints Tuscarora Creek below this little run. Before leaving the discussion of Martinsburg, however, it should be noted that the ice consumed in the city, though mainly of local manufacture, is in part cut on the Tuscarora Creek above the city and in part on Opequon Creek above Tuscarora Creek. The latter source is undoubtedly unsafe on account of the pollution of Opequon Creek by the city of Winchester, and the practice of harvesting ice on it should be prohibited. From the mouth of Tuscarora Creek, Opequon Creek flows for a few miles through a farming country to the Potomac.

POTOMAC RIVER FROM OPEQUON CREEK TO ANTIETAM CREEK.

On the Potomac, 20 miles below Opequon Creek, is Shepherdstown, a village with no public water supply and but few wells, most of the inhabitants using cistern water. There is no sewerage system, but a small run which courses through the town performs the functions of one. It is lined with privies and hogpens, which pollute it badly. The town is too small to contaminate the Potomac greatly, but its contribution of excrement should not be overlooked, for small outbreaks of typhoid fever are very likely to occur in places without water supply and sewerage, and the disease can easily be disseminated by means of infected feces through the agency of the river. Six miles below Shepherdstown is the mouth of Antietam Creek.

ANTIETAM CREEK.[a]

Antietam Creek rises in the Green Ridge Mountains, Franklin County, Pa., and discharges into the Potomac 5 miles below Sharpsburg. On Little Antietam Creek is the town of Mont Alto, which furnishes some indirect pollution to the stream. Between East Branch and Little Antietam Creek, in Franklin County, is the borough of Waynesboro, which contains several large industrial plants, but none of them have liquid wastes. The Frick Company, however, runs the sewage of its 700 employees into Little Antietam Creek through an open sewer. The water supply of Waynesboro is well adapted to boiler use, and gives general satisfaction. It is derived from two sources. One of them, Bailey Spring Run, is 4 miles northeast of the town. The reservoir was constructed in 1885, and is now rarely used, being simply a reserve which can be called on in case of emergency. The main supply of the town is derived from Rattlesnake Run, across which a dam has been built at its confluence with East Branch of Antietam Creek in the Pennsylvania Forest Reserve. From this point the

[a] Results of stream measurements on Antietam Creek at Sharpsburg are given on pp. 82-90.

er is carried 7 miles southward and served to the town. There o sewerage other than an irregular system of drains, which are posed to exclude soil. The cesspools, which are universally used, n through the broken limestone, presumably to one or the other he branches of the Antietam. The result is that practically all the s of the town are polluted, and have been abandoned both on this unt and because the water is hard and not adapted to domestic anufacturing use.

he next town of importance below Waynesboro is Hagerstown, a e industrial center of western Maryland. Its public water supply urnished by the Washington County Water Company, and is ved from runs on South Mountain, 11 miles from the city. The ent waterworks were started in 1896 and completed in 1903. ir capacity is 1,500,000 gallons in twenty-four hours; that of the works, established in 1881, was 400,000 gallons. In 1902, owing he depleted condition of the reservoirs, it was found necessary to blish a pumping station on Antietam Creek at Bridgeport. ter was pumped for thirty days only, and since that time this ce has never been used, but it is still available. Hagerstown no regular sewerage system, but is pretty thoroughly drained by a-cotta pipes, which are supposed to exclude all soil. Slops, how-, undoubtedly enter these pipes. Fifty per cent of the houses e water-closets; the rest depend on privies. Cesspools which e the water-closets are in many cases abandoned wells, and esti-es have been made that 40 per cent of them are so. Privy-vault ter is sometimes buried in the town, but more commonly it is car- outside of the city limits and disposed of on farms. Owing to fact that cesspool drainage and other pollution finds its way ugh the crevices and seams in the rocks that underlie the town he general water level, most of the wells have become polluted, consequently many of them have been closed up. The fact that nsiderable number of typhoid cases occur every year in Hagers-n and that these are as a rule confined to users of well water seems ndicate that the remaining wells should be abandoned. The indi- pollution is probably largely carried off by Town Run, a tribu- of Marsh Run, which in turn enters Antietam Creek. Town n receives the condenser water and washings from beer barrels of Hagerstown Brewery Company, which claims that it is this flux ater alone that keeps the run from stagnating and becoming very l and offensive in summer time. The Blue Ridge Knitting Com-y does considerable dyeing not only for itself, but for other firms Maryland and Pennsylvania. Its wastes are spent dyes and rinse er from the finished goods and amount to 2,400 to 3,600 gallons wenty-four hours. They are disposed of in the Town Run. J. C. ilette & Co. bleach their goods, and the rinse water, amounting

to 3,500 gallons in twenty-four hours, and the wasted spent bleach enter Marsh Run. The Antietam Creek Paper Company is located outside of Hagerstown, and makes paper from wood, rags, and paper by the soda process. The most important waste is spent lime bleach, which is sedimented near the mill and applied to a farm owned by the company.

Below its confluence with Marsh Run, Antietam Creek receives important pollution from but one other source—the town of Sharpsburg, Md., located on a little run a short distance from the creek. The town is a small one, but it is near the battlefield of Antietam, and therefore is periodically visited by crowds who severely tax its limited sanitary facilities. The run on which it is located heads in a spring which is in common use as a water supply, though the inhabitants have to go to it for water. In the summer of 1904 there was a typhoid epidemic which some persons attributed to the use of the spring water. At that time there was a general cleaning out of the privy vaults and hog pens that line the run, and now very few of the hog pens directly overhang it, though it undoubtedly receives much fecal matter of both man and animals. While the amount must be small in proportion to pollution from other sources, it is perhaps important because Sharpsburg is but 60 miles above Washington, where the Potomac is used as a public water supply, and pollution from Sharpsburg would probably reach Washington in a day or two.

POTOMAC RIVER FROM ANTIETAM CREEK TO SHENANDOAH RIVER.

Elk Branch, which enters the Potomac a little above Harpers Ferry, receives the sewage of Shenandoah Junction, W. Va., where a considerable number of travelers find victuals and temporary lodging. Ten miles below the mouth of Antietam Creek, at Harpers Ferry, the Potomac is joined by the Shenandoah. The town is situated on the tongue of land between the rivers and is unsewered, so that various ways are adopted to get the soil into the Potomac, where practically all the refuse of the town goes. The Baltimore and Ohio station is right on the river, into which its water-closets conveniently discharge beneath the railroad bridge. The subject of the sanitation of the railroads in the Potomac basin is not an unimportant one, for besides the stations, which are, of course, fixed and can always be carefully provided for, there are 1,200 miles of track over which pass every day many hundreds of people from all parts of the Union, many of them from cities and towns in which typhoid fever is common. The usual method of caring for the excreta of these travelers is to let it drop along the tracks. It has generally been assumed that this is the best way of handling this material, but it seems a fair question whether it is or not. Undoubtedly the method was originally adopted because of its simplicity, and it has received general acceptance without much

ıought as to its possibilities for spreading infection. Perhaps in ıe future this problem will receive more careful attention and some ;her means of disposing of the feces, such as collecting them and aving them at definite points for disposal, may be adopted.

One of the hotels in Harpers Ferry has its fixtures connected to a sspool, the overflow of which is piped to the river. Another is con-ected by a sewer to the old arsenal yard, where abandoned raceways ınduct the sewage to the river. It is said that not a few private ɔuses dispose of their sewage in the same way. Privies are common . Harpers Ferry, and the vault matter is disposed of as suits the wners; it is believed that some of them throw the soil into the rivers. here is no public water supply, the people for the most part relying ɑ cisterns, though a few take water from the brewery, which brings s water from springs in the Blue Ridge Mountains across the bed of ıe Shenandoah. The Hill Top Hotel pumps some of its water from 'otomac River. The only industrial wastes in Harpers Ferry are hose of the brewery and two pulp mills, one of which is on the Poto-ıac and the other on the Shenandoah. Both mills manufacture ıechanical wood pulp, in which process the logs are freed from their ıark before being ground (Pl. VIII, *B*, p. 222). The shavings were ormerly disposed of by being put into the rivers, and at the time of he inspection evidences of this pollution were very manifest. Since hat time both mills have installed apparatus for burning the shavings ınd the nuisance is abated. The brewery discharges the washings rom its beer kegs into the Shenandoah.

POLLUTION IN SHENANDOAH RIVER BASIN.

Shenandoah River is formed at Riverton, Va., by the confluence ɨf North and South forks. South Fork in turn is formed at Port ɾepublic by the junction of North and South rivers.

SOUTH FORK OF SHENANDOAH RIVER BASIN.

SOUTH RIVER.[a]

South River rises west of Greenville, Augusta County, W. Va., and lows eastward past Basic City and Waynesboro, towns on opposite ɔanks of the river, forming a considerable center of population. Here ;he stream receives its initial industrial pollution. Basic City has a small ɔlanket factory and a factory for the manufacture of tanning extract ɾom chestnut-oak wood. The pollution furnished by the former con-ıists of rinse water from the finished goods, and from the latter, at ;he present time, such amounts of extract as are absorbed by the ondenser water. When the plant was new the leaching vats leaked ınd caused much complaint because the extract stained the river

[a] The results of measurements of South River at Basic City and Port Republic are given on pp. -98.

badly. Several factories have located at different times in Basic City, but their existence has been short. A large summer hotel annually attracts many visitors. The city is supplied with water from a spring close to the river. There is no sewerage system, but one of the hotels has a private sewer which discharges into a run that enters North River below the waterworks.

Waynesboro is supplied with water from Bakers Spring, which is owned by private parties, and for the use of which the town pays a small sum every year. The mains and service pipes, together with a storage tank of 50,000 gallons capacity, are owned by the town, and were installed in 1897 at a cost of $10,000. The introduction of this supply reduced the typhoid rate and has led to the general abandonment of wells. A stove factory is the largest industrial plant in Waynesboro. It has no liquid wastes, but the sewage from its 100 employees is discharged into a race which enters the river. Brunswick Inn is also reported as sewering into the river, and it is said that the material from the many privies in town is thrown into it. The slaughterhouses in both Waynesboro and Basic City dispose of their offal in the stream.

From Basic City South River flows in a northerly direction. At Crimora a small run enters, which is very turbid owing to the washing of manganese ore by the Crimora Manganese Company near its head. This concern employs 100 men, who are established in small huts scattered over the watershed of the run. A long tunnel is being driven in the mines which will drain them more thoroughly and deliver the water on lands of the company instead of to the run. It is proposed to construct settling basins to clarify the water, which will then be led, in some way not determined, to the river.

NORTH RIVER.[a]

North River rises in the Shenandoah Mountains in the northwest corner of Augusta County, on the slopes of Briery Branch Knob. The upper part of its watershed is given over to lumbering, and at Stokesville, just east of Narrow Back Mountain, are located a sawmill and a tanning-extract factory. The latter is still uncompleted and unless unusual precautions are taken when the plant is started, the leaking vats may discolor the river. In the summer of 1905 this town was the seat of an outbreak of typhoid fever. The first case, which was probably imported, was in a family whose spring was in common use in the town. About two weeks afterwards two other users of the waters of this spring were taken sick. One of them was removed to the west end of the town, where he remained for a few days, after which he was taken to Harrisonburg. In this interval he apparently infected a privy which was used by several families,

[a] The results of stream measurements in the North River basin are given on pp. 98-108.

ıted directly opposite the house where he was confined. Later, ıoid germs from this source must have been disseminated in the hborhood by flies, for 4 cases appeared close by and they were only ones in the whole town among those who did not use the ıg water. Other cases, 13 in number, occurred among the users ıe spring and people who lived along the run which rises in it, who either had access to the spring itself or used the water of run for one purpose or another in their homes. This epidemic trates very well how typhoid fever originates and spreads in the n of the Potomac. As a rule, the outbreaks occur in small towns re there are no facilities for disposing of ordure and where the ed water supply is in general use and is derived from some ce surrounded by dwellings. Sanitary precautions, through the rance of the people, are entirely neglected and twelve months in year conditions are ripe for an outbreak of typhoid. All that eded is to have the initial case imported. Once that is accom- ıed, the disease spreads rapidly. In many towns where repeated reaks have occurred, the disease may be said to have established f permanently, a case or two being present all the time. This can eadily understood, for the stools are not sterilized, and it needs a transportation of privy matter or some other infectious mate- to start fresh cases.

ıe next town below Stokesville is Bridgewater, which also has subject to outbreaks of typhoid fever. There is no public water ly, the people being dependent on cisterns and wells. On the somewhat west of the town is a woolen factory where blankets nade. It is run only part of the year and the wastes, consisting small quantity of wool scourings, spent dyes, and rinse from the ıed goods, are emptied directly into North River.

elow Bridgewater is Mount Crawford, located on North River ewhat to the west of Cooks Creek.[a] Typhoid has been prevalent , which may perhaps be partly accounted for by the fact that citizens have cut and used ice from Cooks Creek, a stream receiv- he sewage of Harrisonburg.

arrisonburg is about 8 miles northeast of Mount Crawford. It ıe of the largest cities in the valley and seems to be growing lily. It has a public water supply derived from Dry River, 13 s farther west. It is said that since the supply was introduced oid, which was formerly very common, has been materially re- d. The sewerage system is a combined one and is available in ly all parts of the city. The flow, which is estimated at 250,000 ns in twenty-four hours, is discharged a quarter of a mile south ıe city into Blacks Run, a tributary of Cooks Creek. This sew- is augmented by the waste from the plant of the J. P. Houck

[a] The *results of measurements* of Cooks Creek at Mount Crawford are given on pp. [illegible].

Tanning Company, estimated at 2,500 gallons a day. The waste from the lime vats is sedimented and the liquor run into the sewer, as is the waste sour bark liquor. The liquor from the scouring machines and a waste made up of various small leakages that occur in various parts of the tannery are turned directly into the run. Together they make the water very foul, especially in summer, when the city authorities have occasionally been obliged to flush out the stream on account of the bad odors arising from it. Whenever observed, the run has appeared to be taxed to its utmost, and it is reported that in summer the waste from the tannery has decidedly discolored North River as far as Mount Crawford railroad station. No other factories in Harrisonburg have liquid wastes.

Four miles above Port Republic North River receives Middle River, which rises in Little North Mountain southwest of Staunton. Middle River flows northeastward to Long Glade, then southeastward to Laurel Hill, where Lewis Creek enters.[a] This creek is heavily polluted by the sewage of Staunton, an energetic, prosperous city estimated to have 12,000 buildings, 50 per cent of which are connected with the sewer. There are no manufacturing plants having liquid wastes; therefore the sewage is almost entirely domestic. The system, which is a combined one, was established twenty-five years ago and has grown slowly and irregularly ever since. The first water supply was introduced in 1849 and is still in use, but the main supply was put into service in 1876, at a cost of $100,000, and comes from springs on the bank of a stream one-half mile west of the city. The wells of the city are badly polluted and most of them have been closed up by the local authorities. The typhoid rate of the city is very low, only one death being recorded in 1904.

The water supply of Staunton was at one time unpleasantly affected by fresh-water sponge which grew in one of the reservoirs. The trouble was investigated by Prof. J. W. Mallet, whose report is on file with the city authorities. The sponge was killed and the trouble completely overcome by fluctuations of the water level.

SOUTH FORK OF SHENANDOAH RIVER BELOW PORT REPUBLIC.

Below Port Republic, South Fork of Shenandoah River flows northeastward through the Page Valley, being separated by Massanutten Mountain from North Fork, which joins it at Riverton.

Keezletown is located on the west side of the mountain, but discharges its refuse into South Fork through Cub Run. It is a small town, but the run receives some pollution there from the tannery of A. D. Bertram, which has a capacity of 700 hides a year.

[a] The results of measurements of Lewis Creek near Staunton are given on pp. 101–103.

little below the mouth of Cub Run South Fork receives Stony which rises on the east side of the mountain and flows through heysville, where it is contaminated by a tannery having a city of about a hide a day.

Elkton South Fork is much befouled by the waters of Elk Run, n rises in the Blue Ridge Mountains and flows westward to the .[a] Elkton has a public water supply which is furnished from gs by the Wampole Lithia Company. There is no sewerage; the bitants depend entirely on outhouses, the soil of which is said to rown into Elk Run when they are cleaned. One of the hotels has nch for its urinal and slops which leads directly to the run. The m also receives pollution from the tannery of J. R. Cover & Sons. plant employs 25 hands, and has a privy directly overhanging a . that leads to the run. Through this ditch are discharged the es, which amount to 1,500 gallons a day. Inspection makes it evident that this amount is too large for the little run to carry romptly and easily. Indeed, the effect of the pollution on the itself must be considerable. In the summer a hotel is opened lkton which is said to accommodate many guests. While such s add to the wealth of the towns that are fortunate enough to ss them, they contain an element of danger, for their patrons from many different places and may carry in their persons s of disease contracted in their homes. In due time these tunates sicken and then the infection elaborated by them is to lay hold of the community they are visiting and make it a r from which contagion spreads.

low Elkton is Shenandoah, a prosperous town which can pollute iver but indirectly. Thirty miles below is the mouth of Hawks- reek, on which is located, in Page county, the town of Luray.[b] creek divides the town into very nearly equal portions which omewhat abruptly from it; consequently the run-off through own is quick and carries with it considerable refuse. A water ly was installed in 1900. Typhoid fever is said to have been prev- prior to its introduction, but such is not now the case. There regular sewerage system in town, and cesspools are commonly As a rule they do not need cleaning, because they leak away gh the underlying limestone. A number of water-closets and f the hotels discharge directly into Hawksbill Creek. At one there was some agitation against permitting them to do so, but d out, and now the suggestion has been made that the town lish a sewerage system and utilize the creek for an outlet. y has usually a large transient population, attracted thither by

[a] Results of measurements of Elk Run at Elkton are given on pp. 110–112.

[b] Results of measurements of Hawksbill Creek at Luray are given on pp. 112–115.

the wonderful caverns. Thus the town is considerably exposed to the danger of infection being imported from outside. The chief pollution of Hawksbill Creek is by the Luray tannery, owned by the Deford Company, of Baltimore. This plant employs 170 hands, and the waste poured into the creek amounts to 10,000 gallons a day. The waste from the beam house and the scouring liquor are run into two cesspools, where they are allowed to evaporate. The residue is used for a fertilizer on a farm owned by the company. The volume of sour bark liquor, which with the soil of six water-closets is carried in a long trench to the creek, is so large in proportion to that of the stream that the latter is colored a deep red and maintains the hue to its mouth, 5 miles below the factory. An acetylene-gas company in the center of the town piles its lime sludge on the banks of the Creek.

NORTH FORK OF SHENANDOAH RIVER BASIN.

North Fork of the Shenandoah rises in the northern part of Rockingham County and flows southeastward to Broadway, where it turns to the northeast. North Fork is not much polluted until it reaches New Market, where, on a tributary of Smiths Creek, there is a small tannery owned by F. M. Tusing. The next town below is Mount Jackson, which is on Mill Creek a little way from its mouth. It has neither public water supply nor sewerage, the people relying almost wholly on cistern water, as there are but a few wells in town. The pollution here is inconsiderable and very indirect. From Edinburg to Strasburg the course of North Fork is decidedly meandering. At Tomsbrook a creamery pollutes North Fork. At Woodstock a creamery pollutes Hollow Run, but the rest of the refuse of the town is insignificant. There is no public water supply nor sewerage, and the river receives only a little very indirect pollution from the town.

Strasburg is the largest town in the valley of North Fork of the Shenandoah. It is traversed by Hupp Spring Run, and this stream carries off most of the waste from the town, and is also polluted by the sludge from a small acetylene-gas plant and by the effluent from O. F. Chandler's tannery, which has a capacity of about a hide a day. At the time of inspection Strasburg was depending on springs and wells, but as the well water is very hard a public water supply was being installed which it was expected to follow up with a sewerage system.

The only other town to be noticed in the discussion of North Fork is Middletown, a place without water supply and sewerage, located on Marsh Run, a tributary of Cedar Creek, which flows into North Fork below Strasburg. The pollution from Middletown is only slight and very indirect.

SHENANDOAH RIVER BASIN BELOW NORTH AND SOUTH FORKS.

Riverton lies between North and South forks of Shenandoah River ıd pollutes the rivers but little, as it is a small place, with most of ıe houses some distance from the two streams. The town pur-ıases its water from Front Royal, and therefore enjoys the same nmunity from typhoid as that town. There is a large duck farm ⁄hich drains into the North Fork of the Shenandoah. No other pol-ution here is worthy of note.

A short distance below Riverton, Shenandoah River receives the lrainage of Front Royal, which is on Happy Creek, 3 miles from its nouth. Most of the pollution of the creek by the town is indirect, 'or there are few water-closets, most of the people using outhouses, hough some of the privies are dangerously near the stream. One)f the hotels has a cesspool from which the overflow is carried in a)rivate sewer toward the creek. The town is a clean one, and is free 'rom typhoid fever. The chief source of pollution on the creek is a laughter barn. The offal is fed to swine kept in a yard that reaches lown to the creek in order that the animals may drink there. When)bserved, no slaughtering was being done, but that considerable)ffal and blood goes into the creek when killing is in progress seems o be the general opinion. Formerly there used to be many cases)f typhoid fever in Front Royal every year, but this stopped twelve 'ears ago, when a public water supply was introduced from Chester ıap, 4 miles to the southeast. The source of supply is from springs ⁄hose flow is collected in a reservoir of 1,500,000 gallons capacity and ın by gravity into the town. The cost of the works was $40,000.

Twenty-four miles below Riverton is the mouth of Lewis Run, hich drains the town of Berryville, the county seat of Clarke)unty. There is no manufacturing in Berryville, but the run is pol-ted by hogpens and privies which are near it. Moreover, many of e houses have sewers for their slops which empty into the run. The wn has a public water supply which is said to be excellent. Pre-ous to its introduction, typhoid was rampant in the town and now is of rare occurrence.

Fifteen miles below Berryville Evitt Run enters the Shenandoah. ıis is a rather attractive stream of clear water, which does not ow ocular evidence of pollution, though it carries the indirect pol-tion of Charles Town, the county seat of Jefferson County. This ty has no sewerage system and has not been compelled to construct ıe because of the fact that if there are not seams enough in the lime-one to carry away the leakage of the numerous cesspools, the explo-)n of a dynamite cartridge in the rock at the bottom of the cesspool sufficient to insure its caring for itself. The water supply of the

town was originally obtained from several town pumps, all but two of which have been given up because the above-mentioned method of caring for sewage has allowed cesspool matter to enter the wells.

The present water supply is sufficient and satisfactory. It is furnished by the Charles Town Water and Manufacturing Company, which brings it from a spring 1 mile west of town.

Between Evitt Run and Harpers Ferry Flowing Run enters the river. This stream is contaminated by the paper box board factory of Eister & Sons at Halltown, W. Va. The firm makes box board from old paper, and the effluent, consisting of dirty water with much paper and fiber in suspension, is turned directly into the run and muddies it. Additional pollution is furnished by the privies of the concern, which overhang the stream for the convenience of its 35 employees.

POLLUTION IN POTOMAC RIVER BASIN BELOW SHENANDOAH RIVER.

POTOMAC RIVER FROM SHENANDOAH RIVER TO MONOCACY RIVER.

At Harpers Ferry the Potomac cuts through the Blue Ridge Mountains between Loudoun Heights on the south and Maryland Heights on the north, and enters the upper Coastal Plain region. Along the northern bank there is a scattered population, most of whom are densely ignorant of sanitary laws. The privy vaults and hogpens are near the houses except where there is a little stream, in which case the structures are located over it, and thus the offal is carried to the river. At Weverton and Knoxville, Md., this population is somewhat concentrated, and at Knoxville the privies and hogpens which overhang the creek that passes through the town are more numerous than is usual in this region. The migratory character of the population in these towns and the accompanying crude sanitary conditions constitute a decided menace to the river. During the summer of 1905 typhoid fever prevailed in these settlements, and probably if records could be obtained for the past dozen years it would be found that it had done so every year. They are not more than 35 miles from Washington, and should be subjected to rigid sanitary supervision.

Below Knoxville is Brunswick, Md., a town which has sprung into existence on account of the location of the Baltimore and Ohio Railroad shops there. These shops employ 400 men, and while there are no liquid wastes the sewage of the employees furnishes the Potomac with considerable indirect pollution. The privy which is used by the roundhouse force is located close to the canal and is nearly surrounded by a green pool caused by seepage from it; about 100 yards distant is another privy in a large cinder bed. The town is on a high, steep hill and is crossed by four different runs along which are a number of privies, some of them actually overhanging the streams.

nd Culvert Run furnishes the most important pollution, for into discharged the sewage of the railroad bunk house, which is fitted i water-closets, bath tubs, and urinals. This sewage is created a roving population, and consequently by one more exposed to ase than a settled one would be, and the excrement is correspondy more dangerous. It is expected that a large Y. M. C. A. buildwill be erected alongside the bunk-house, and that too will disge into the run. There are a few water-closets in the town, some hich are connected to the runs, but in general privies are used. water the town is dependent on wells and cisterns, though at east end of town there is a private supply which comes from the omac. The peculiar topography and population of Brunswick e it very necessary that sanitary matters be thoroughly looked r there. The fact that it is on the steep sides of a high hill insures the offal finding its way promptly to the river, and the shifting ulation, however well intentioned it may be, is more or less likely bring disease into the community from without. Finally, the n is near Washington, and therefore typhoid germs will be transted by the Potomac to that city in a short time. In the summer 905, at the time the inspection was made, it was reported that e were five cases of typhoid fever in Brunswick, but what precaus were taken to sterilize the stools and otherwise protect the lic were not ascertained.

few miles below Brunswick the Potomac receives Catoctin Creek Virginia and Catoctin Creek of Maryland, after which it cuts ugh Catoctin Mountains and emerges at Point of Rocks, in the er Coastal Plain region. Point of Rocks and Washington Junc- form a single settlement skirting the Chesapeake and Ohio al.[a] Like the other places below Harpers Ferry, they are lacking sanitary arrangements. At Washington Junction the wateret of the railroad station discharges into the river. From Point Locks it is 3 miles to the mouth of Tuscarora Creek, on which at mstown there is a small cannery. The creek is also polluted at ibs.

MONOCACY RIVER BASIN.

wo miles east of South Tuscarora Creek Monocacy River enters Potomac. It has three large feeders that rise in Adams County — sh, Rock, and Middle creeks. Between the two former, on the ershed of Rock Creek, is the borough of Gettysburg, and on dle Creek is the town of Emmitsburg. Gettysburg derives most ts water supply from Marsh Creek, southwest of the town. The ershed above the intake is not heavily polluted, though at Knightstown there is a tannery with a capacity of 100 hides a k. The water is filtered through a Warren filter that was installed

[a] Results of measurements of Potomac River at Point of Rocks are given on pp. 148 161.

twelve years ago. Coagulent is used only when the creek is very turbid. This supply is supplemented and mixed with water obtained from two driven wells on Cemetery Hill. These are pumped by wind power and are constantly in use. The borough is now installing a sewerage system for soil only which when finished will have 7 miles of pipe line and it is expected will be generally utilized by the citizens. The sewage will be treated in two septic tanks, and the effluent from them will be filtered through brick walls and then run into Rock Creek into which the private sewers of the town now discharge. It is to be hoped that the treatment of the sewage will be effective, for Gettysburg is almost daily visited by large numbers of sight-seers. The throng of pilgrims is variable, sometimes being small and sometimes rising to 10,000 in a single day. The people come to see the beautiful battlefield, which has been carefully preserved by the National Government. As the park is a permanent one, there will probably never be any diminution in the number of visitors. In a throng of this kind there are apt to be many who seize the opportunity for a rest because they are out of condition, run down, or sick, and think that a little excursion will restore them. Among such people there are likely to be some in one stage or another of typhoid fever, so that the transient population that visits Gettysburg may be something of a menace to the waters of the Potomac; hence the desirability of carefully purifying the sewage before it is discharged into the creek.

Stevens Run, a tributary of Rock Creek, is polluted by the effluent of a gas works. The waste makes the run ill smelling and repulsive in appearance. Moreover, it is said to injure fish life, and a suit has been brought by the Fish Commission against the company. Culps Run, another tributary of Rock Creek, receives the sewage and effluents from W. S. Duttera's tannery, which turns out 50 hides a week, and the wastes from which are similar to those discharged from other tanneries.

Emmitsburg, on Middle Creek, is the site of Mount St. Mary's Academy, St. Joseph's Academy, and the mother house in the United States of the Sisters of Charity. The population of the town, including the sisterhood, is 2,000. There is neither public water supply nor sewerage.

On Double Pipe Creek is Westminster, a large town without public water supply or sewerage.

From the junction of Marsh and Middle creeks to the mouth of Carroll Creek the distance is 25 miles. Carroll Creek rises in Catoctin Mountain, northwest of Frederick, Frederick County, Md., and flows southeastward through the southern part of the city to the Monocacy. The Frederick water supply is obtained from Big Tuscarora Creek, Little Tuscarora Creek, and Fishing Creek and is said to be wholesome, a statement that is borne out by the low typhoid rate of the city.

ıch of the two main streets has a single drain, which was put in pri-ıarily with the object of carrying off the water from cellars of abut-ıg houses. They have developed into sewers from which soil is :cluded, but which take in slops and surface water and discharge to Carroll Creek. In many of the streets of the city the slops run ırough the gutters and ultimately reach the creek.

The indirect industrial pollution of Carroll Creek consists of an significant amount of waste from a cannery and from the scrubbers ! a gas house. It is directly contaminated by the scouring liquor om the Brierly tannery, together with some lime sludge that is piled ı the banks of the creek; by the effluent from a steam laundry, by ıe sewage of the Carroll County almshouse, and, most obviously, by ıe pollution from the works of the Union Knitting Company, con-sting of the sewage of 200 employees and a large quantity of spent ?es.

The pollution received by the Monocacy from the mouth of Carroll eek to the Potomac is, for the most part, very insignificant, being ly that incident to the life of widely separated farms. At Fred-ick Junction the closets of the Baltimore and Ohio Railroad station ıpty into the river. Buckeystown is the most considerable settle-ent below Frederick on the Monocacy. It is drained by a little run ıich receives the washings of a cannery and a small creamery, besides e discharge of water-closets. The unvaulted privies of a large brick ɔrks in the town are about 20 feet from the stream. The water used Buckeystown is derived from cisterns.

POTOMAC RIVER FROM MONOCACY RIVER TO GREAT FALLS.

The largest and most important tributary of the Potomac between .e mouth of the Monocacy and Great Falls is Goose Creek. It has large drainage area, which is on the south side of the river and lies ıst of the Blue Ridge Mountains. The watershed is given over to ;riculture and contains but one town of much size. Hence the prox-ıity of the basin to Washington is not nearly so important as it ould be if the population was large and concentrated at a few points. he development of this drainage area will be watched with interest, ır should it become the home of a large summer population, or should :her considerable towns spring up in it, the creek might become a ;rious menace to Washington, inasmuch as disease germs from it ɔuld be transported to the city in a few hours.

Leesburg, the important town alluded to, is on Tuscarora Creek, a ibutary of Goose Creek. There is no sewerage system in the town, ıt 800 feet of 2-foot terra-cotta drains, which are supposed to carry rface water only, discharge into Tuscarora Creek. Therefore the ɔllution caused by Leesburg is indirect save for the few privies that erhang Tuscarora Creek. The water supply of the town is inade-ate and was suspected at one time of being contaminated, for in the

summer of 1904 there was considerable typhoid fever, and this impelled the citizens to bond the town for $30,000 to enable it to increase its water supply. The new system will furnish an abundant supply and will probably result in the construction of a complete sewerage system, which will have its outlet in Goose Creek.

Eight miles above Great Falls is Seneca Creek, whose watershed is given over to small farming and which does not contain a single important center of population. The creek would not be worth mentioning here did not its proximity to Washington make it possible for disease germs originating in its basin to be transmitted to the capital in a very short time.

POPULATION AND DRAINAGE AREAS.

The following tables show the population and the drainage areas of the smaller basins that make up the Potomac watershed:

Population of the Potomac River basin.

[According to the census of 1900.]

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
NORTH BRANCH POTOMAC RIVER BASIN.			
	Miles.		
Savage River	209		1
Swanton		87	
Other towns		87	
		174	
Georges Creek	207		13
Barton		1,287	
Frostburg		5,274	
Lonaconing		2,181	
Midland		1,800	
Ocean		1,500	
Other towns		1,194	
		13,236	
Wills Creek	174		11
Cumberland		17,128	
Eckhart Mines		1,600	
Hyndman		1,242	
Jennings Run			
Mount Savage		2,000	
Vale Summit		800	
Other towns		2,623	
Estimated remaining population on Wills Creek and tributaries		6,000	
		31,493	
Evitts Creek	169		
Cumberland Valley		157	
Hazen		104	
Other towns		142	
Estimated remaining population on Evitts Creek and tributaries		1,500	
		1,903	
Patterson Creek	166		4
Alaska		183	
Burlington		259	
Medley		140	
Other towns		483	
		1,065	

Population of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
RANCH POTOMAC RIVER BASIN—continued.			
	Miles.		
otomac River	158		
		540	
		395	
		496	
		581	
		344	
		2,536	
		2,115	
		1,998	
		510	
		1,434	
maining population on the North Branch and itaries		15,000	
		25,949	
North Branch Potomac basin		73,820	
UTH BRANCH POTOMAC RIVER BASIN.			
otomac River	158		14
		119	
		205	
		246	
		460	
		312	
		102	
		580	
		142	
maining population on South Branch and tribu-		18,000	
		21,597	
BASIN BELOW NORTH AND SOUTH BRANCHES.			
nd Fifteenmile creeks			4
		147	
		250	
		100	
		224	
maining population on Town, Fifteenmile, and eks		11,070	
		11,791	
iver	152	2,423	11
iver	122		18
		126	
e		193	
on		66	
		40	
		55	
		152	
		1,036	
maining population on Great Cacapon River aries		10,800	
		12,468	
y Creek	112		19
		151	
		113	
		529	
maining population on Great Tonoloway Creek aries		1,600	
		2,393	
tributaries	107	2,941	20

Population of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
POTOMAC BASIN BELOW NORTH AND SOUTH BRANCHES—cont'd.	*Miles.*		
Licking Creek	105		
McConnellsburg		572	
Plumrun		110	
Sylvan		190	
Webster		122	
Other towns		466	
Estimated remaining population on Licking Creek and tributaries		6,200	
		7,660	
Back Creek	96		
Baxter		102	
Hedgesville		342	
Shanghai		143	
Other towns		923	
Estimated remaining population on Back Creek and tributaries		6,500	
		8,010	
Conococheague Creek	90		
Ambersons Valley		312	
Chambersburg		8,864	
Dryrun		230	
Fannetts		314	
Fort Loudon		335	
Greencastle		1,463	
Mercersburg		956	
St. Thomas		410	
Williamsport		1,472	
Brownsville		1,552	
Fayetteville		672	
Other towns		3,987	
Estimated remaining population on Conococheague Creek and tributaries		6,744	
		27,311	
Opequon Creek	78		
Bruceton		398	
Bunker Hill		228	
Darkesville		231	
Gerrardstown		239	
Jordan Springs			
Kearneysville		303	
Martinsburg		7,564	
Middleburg		466	
Winchester		5,161	
White Post		250	
Other towns		1,167	
Estimated remaining population on Opequon Creek and tributaries		8,840	
		24,647	
Antietam Creek	56		
Antietam		163	
Benevola		103	
Blue Mountain		100	
Boonesboro		700	
Breathedsville		114	
Cavetown		287	
Chewsville		152	
Downsville		152	
Eakles Mills		120	
Fairplay		114	
Fiveforks		113	
Funkstown		559	
Hagerstown		13,591	
Keedysville		426	
Leitersburg		347	
Mont Alto		658	
Pondsville		100	
Quincy		410	
Ringgold		114	

tion of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
RTH AND SOUTH BRANCHES—cont'd.			
	Miles.		
		186	
		1,030	
		462	
		5,396	
		1,201	
ulation on Antietam Creek and trib-		16,342	
		42,940	
	203		
		384	
		425	
		3,521	
		225	
		330	
		172	
		175	
		284	
		1,026	
		6,542	
	208		
		239	
		120	
		300	
		197	
		124	
		100	
		7,289	
		936	
		9,305	
	203		
		328	
		381	
		200	
		381	
		856	
		1,749	
		3,895	
ah River	102		
		127	
		197	
		143	
		511	
		1,005	
		225	
		1,147	
		375	
		1,220	
		225	
		1,353	
		6,528	
	108	205	
ah River	102		
		400	
		512	
		143	
		176	
		104	
		105	
		250	
		125	
		100	
		423	
		153	
		153	

Population of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimat popula per sq mile
POTOMAC BASIN BELOW NORTH AND SOUTH BRANCHES—cont'd.			
Shenandoah River basin—Continued.			
North Fork of Shenandoah River—Continued.	*Miles.*		
Mount Jackson		472	
New Market		684	
Riverton		650	
Singers Glen		108	
Strasburg		690	
Timberville		173	
Toms Brook		280	
Woodstock		1,069	
Other towns		2,322	
		9,092	
Shenandoah River below confluence of North and South forks.	49		
Berryville		938	
Bolivar		781	
Boyce		275	
Charles Town		2,392	
Halltown		115	
Kabletown		106	
Millwood		400	
Stephens City		490	
Summit Point		217	
Other towns		590	
		6,304	
Estimated remaining population in Shenandoah River basin		74,500	
Total population in Shenandoah River basin		116,171	
Catoctin Creek, Maryland	38		
Bolivar		112	
Burkittsville		229	
Harmony		126	
Jefferson		320	
Middletown		665	
Myersville		150	
Petersville		210	
Wolfsville		110	
Other towns		360	
Estimated remaining population on Catoctin Creek, Maryland, and tributaries		6,000	
		8,282	
Catoctin Creek, Virginia	33		
Hillsboro		131	
Other towns		721	
Estimated remaining population on Catoctin Creek, Virginia, and tributaries		2,000	
		2,852	
Monocacy River	27		
Barnesville		125	
Boneauville		139	
Bruceville		137	
Buckeystown		430	
Cashtown		146	
Catoctin		150	
Creagerstown		132	
Double Pipe Creek		100	
Emmittsburg		849	
Fairfield		395	
Fountaindale		172	
Frederick		9,296	
Gettysburg		3,495	
Graceham		185	
Harney		150	
Johnsville		106	
Lewistown		235	
Liberty Town		580	
Lime Kiln		400	

Population of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
BELOW NORTH AND SOUTH BRANCHES—cont'd.			
Continued.	*Miles.*		
		1,118	
n		148	
		140	
		100	
		360	
		100	
		430	
y		117	
		146	
		180	
		115	
		143	
		665	
		175	
		663	
		250	
		309	
		240	
		219	
		359	
		3,199	
		400	
		175	
		4,583	
maining population on Monocacy River and			
		55,000	
		86,661	
	18		35
		147	
		175	
		150	
		364	
		1,513	
		175	
		250	
		296	
		168	
		172	
		247	
		111	
		351	
		140	
		104	
		376	
		838	
naining population on Goose Creek and tribu-			
		8,000	
		13,577	
	16		14
		203	
		336	
naining population on Broad Run and tributa-			
		550	
		1,089	
	12	848	38
	11		50
		125	
		125	
		150	
		547	
		170	
		236	
		557	
naining population on Seneca Creek and tribu-			
		4,600	
		6,510	

Population of the Potomac River basin—Continued.

	Distance of mouth above Great Falls.	Population.	Estimated population per square mile.
POTOMAC BASIN BELOW NORTH AND SOUTH BRANCHES—cont'd.			
Potomac River and minor tributaries below North and South branches	*Miles.*		
Adamstown		256	
Berkeley Springs		781	
Brunswick		2,471	
Clear Spring		474	
Darnestown		148	
Great Cacapon		131	
Hancock		824	
Harpers Ferry		896	
Knoxville		363	
Magnolia		153	
Oldtown		112	
Paw Paw		693	
Point of Rocks		364	
Potomac		127	
Shenandoah Junction		318	
Shepherdstown		1,184	
Sir Johns Run		239	
Weverton		136	
Other towns		2,186	
Estimated remaining population on Potomac River and minor tributaries below North and South branches		15,800	
		27,656	
Grand total: Estimated population on Potomac River and tributaries above Great Falls		501,647	44

Drainage areas of Potomac River and of its principal tributaries at several points in the river basin.

NORTH BRANCH POTOMAC RIVER BASIN.

	Square miles.
North Branch Potomac River above Bloomington, Md	290
Savage River at mouth	120
Georges Creek at mouth	76
North Branch Potomac River at Piedmont, W. Va., including Savage River and Georges Creek	490
North Branch Potomac River at United States Geological Survey gaging station at Piedmont	410
New Creek at Keyser, W. Va	56
Wills Creek at mouth	270
North Branch Potomac River at Cumberland, Md., including New Creek and Wills Creek	800
Patterson Creek below Mill Creek at Burlington	155
Patterson Creek at mouth	280
North Branch Potomac River at junction with South Branch	1,360

SOUTH BRANCH POTOMAC RIVER BASIN.

South Branch Potomac River at Franklin, W. Va	190
South Branch Potomac River at junction with North Fork of South Branch	320
North Fork of South Branch Potomac River below Seneca Creek	240
North Fork of South Branch Potomac River at mouth	320
South Branch Potomac River, including North Fork of South Branch	640
South Branch Potomac River at Moorefield, W. Va	900
Mill Creek at mouth	100

	Square miles.
refield River at St. Seybert, W. Va	155
refield River at mouth at Moorefield, W. Va	300
th Branch Potomac River below Moorefield, including Moorefield River.	1,200
th Branch Potomac River at Romney, W. Va	1,410
th Branch Potomac River at United States Geological Survey gaging tation near Springfield	1,470
th Branch Potomac River at mouth	1,490

OMAC RIVER BASIN BETWEEN SHENANDOAH RIVER AND JUNCTION OF NORTH AND SOUTH BRANCHES.

omac River at junction of North and South branches	2,850
tle Cacapon River at mouth	115
n Creek	190
eling Creek	120
omac River above Great Cacapon River, including Little Cacapon River.	3,390
at Cacapon River at mouth	670
th River at mouth	205
t River at mouth	190
apon River above North River	405
omac River below Great Cacapon River	4,060
omac River at Hancock, Md	4,100
m Spring Run at mouth	16
py Creek at mouth	145
cing Creek at mouth	195
k Creek at mouth	290
at Tonoloway Creek at mouth	125
ocheague Creek at mouth	580
omac River at Williamsport, Md., including Warm Spring Run, Great onoloway Creek, Sleepy Creek, Licking Creek, Back Creek, and Conocheague Creek	5,560
squon Creek at mouth	335
ietam Creek at mouth	305
ietam Creek at United States Geological Survey gaging station near harpsburg	295
omac River at Harpers Ferry above Shenandoah	6,350

SHENANDOAH BASIN.

th River above Bridgewater	295
ks Creek at mouth	42
th River to Middle River	420
th River to South River	805
dle River to North River	365
is Creek at mouth	28.5
th River to North River	245
th, South, and Middle rivers above Port Republic	1,050
h Fork of Shenandoah River at Shenandoah, Va	1,290
ksbill Creek at mouth	94
ksbill Creek at United States Geological Survey gaging station	52
h Fork of Shenandoah River at Overall	1,490
h Fork of Shenandoah River at mouth at Riverton	1,590
h Fork of Shenandoah River at Brocks Gap	215
h Fork of Shenandoah River at Mount Jackson	510
h Fork of Shenandoah River at mouth at Riverton	1,940

	Square miles
South and North forks of Shenandoah River at Riverton	2,630
Shenandoah River at United States Geological Survey gaging station above Millville	3,000
Shenandoah River at Harpers Ferry	3,010
POTOMAC BASIN BELOW SHENANDOAH RIVER.	
Potomac River below Harpers Ferry, including the Shenandoah	9,360
Potomac River at Weverton, Md	9,370
Potomac River at Point of Rocks, Md	9,650
Catoctin Creek, Maryland, at mouth	130
Catoctin Creek, Virginia, at mouth	93
Monocacy River at United States Geological Survey gaging station	660
Monocacy River at mouth	940
Goose Creek	385
Broad Run, Virginia	80
Sugarland Run	22
Seneca Creek	130
Rock Creek	86
Potomac River at Edwards Ferry	11,100
Potomac River at Great Falls	11,400
Potomac River at Chain Bridge	11,500

OCCURRENCE OF TYPHOID FEVER.

CAUSES OF TYPHOID FEVER.

It is now the generally accepted view that typhoid fever is caused by the typhoid bacillus and that only by the multiplication of this organism in the human body is a person brought down with the disease. The bacillus is readily demonstrated in the spleen of those who die from typhoid and is eliminated in the saliva, feces, and urine of the sick. In the latter excretion it is known to be very persistent, so much so that one who has recovered may for a long time thereafter scatter the specific bacteria through this discharge. The evacuations of those not suffering from typhoid never contain the organism. Thus it is that a well or other water supply may be long polluted by dejecta without causing this disease, and may be quickly converted to a plague center by the advent of one stricken with it. Such a person is a menace to the public health, and the infection from him may be diffused in several ways. The simplest of these is by direct contact. Cases are common where those nursing the patient are brought low as a result of handling the discharges or soiled linen of the sick room, and perhaps by using the knives and forks or drinking cups of the sick. Sometimes the infected objects are not confined to the domicile of the patient. Thus in Montclair, N. J., an outbreak was brought about on one milk route by infection spread from an unreported case. The milk bottles were brought into the sick room, where they became infected, and were then returned to the dealer, who used them without sterilizing them. In consequence

typhoid broke out among those of his customers who took their milk in pint bottles, the only kind left at the house in question, none of the other customers being attacked. With the withdrawal of the supply the epidemic ended. It is possible for the disease to be even more widely disseminated by objects handled by the sick. In collecting facts in the Potomac watershed, it was reported that an epidemic had prevailed among the pickers in a certain peach orchard, and it is quite conceivable that the unclean fingers of the laborers may have infected the fruit, which transmitted the disease to the cities where it was marketed.

Unhappily the sickness is not always severe enough to compel its victim to take to bed. He may go about and ease himself not at a single privy, but at the one nearest at hand when necessity is on him. Thus several unsuspected infection centers may be established. Even when the patient is shut up his stools may be thrown, through ignorance or carelessness, without disinfection into a cesspool or privy or, still worse, on the bare ground.

Typhoid is most frequently spread from the ordure of those afflicted, and this is accomplished by several agencies. The common house fly visits such matter to feed and occasionally to deposit its eggs, and, having accomplished the purpose, returns, with its legs and proboscis bedraggled with filth, to the kitchen or pantry and tracks the infection through the food, which then becomes the vehicle of the disease.

This matter was thoroughly investigated by the typhoid-fever commission of the United States Army in 1898. It was found that the flies alternately visited and fed on the infected stools of the soldiers and the food in the mess tents. More than once, when lime had been scattered over the fecal matter in the pits, flies with their feet covered with lime were seen walking over the food. Moreover, typhoid fever was much less frequent among members of messes who had their tents screened than it was among those who did not take this precaution. The disease gradually died out in the fall of 1898 in Camp Knoxville and Camp Meade with the disappearance of the flies, and this occurred at a time of year when in civil practice typhoid fever is generally on the increase. This was not due to the fact that all those susceptible to the disease had developed it, because the army at these places was considerably recruited at this time. It was also found that flies may carry infected material from soiled bedding and bed pans spattered with the discharge of patients. So this commission pointed out that the typhoid patient should be protected from the annoyance of this insect, not only because he will be more comfortable, but in order to prevent the spread of the disease through its agency.

The fly has also the habit of biting the mouth of man, who frequently moistens his lips with his tongue, and may so infect himself.

L. O. Howard[a] enumerates thirteen different flies that are commonly found in houses. Of these, the common house fly he finds to be far the most numerous. In 1900 he made a collection of flies in dining rooms in different parts of the country, and out of a total of 23,087 flies, 22,808 were *Musca domestica* L.—that is, 98.8 per cent of the whole number captured. The remainder, 1.2 per cent of the whole, comprised various species. The next most abundant fly is *Stomoxys calcitrans* L., which is vulgarly called the stable fly. It differs from the house fly in that its mouth parts are formed for piercing the skin, which the house fly's are not. It is a common impression that the house fly bites. This is not true, the impression being given by the presence of stable flies in houses.

Musca domestica commonly lays its eggs upon horse manure. This substance seems to be its favorite larval food. It will deposit upon cow manure, but it has been impossible to rear it in this substance. It will also breed in human excrement and will lay its eggs upon other decaying vegetable and animal matter, but of the flies that infest dwelling houses, both in cities and on farms, the vast proportion come from horse manure. Packard[b] states that at Salem, Mass., he bred a generation in fourteen days in horse manure. The duration of the egg state was twenty-four hours, the larval state from five to seven days, and the pupal state from five to seven days. At Washington, Howard found that in midsummer each female lays about 120 eggs, which hatch in eight hours, the larval period lasting five days and the pupal period five days, making the total time for the development of the generation ten days. This was at the end of June. The periods of development vary with the climate and with the season, and the insect hibernates in the puparium condition in manure or at the surface of the ground under a manure heap. The adult also hibernates in houses, hiding in the crevices. The Washington observations indicate that the larvæ molt twice, and the insect averages, thus, three distinct larval stages. The periods of development were found to be about as follows: Egg from deposition to hatching, one-third of a day; hatching of larva to first molt, one day; first to second molt, one day; second molt to pupation, three days; pupation to issuing of the adult, five days; total life round, approximately ten days. There is thus abundant time for the development of twelve or thirteen generations in the climate of Washington every summer.

The number of eggs laid by individual flies is undoubtedly large, averaging about 120, and the enormous numbers in which the insects occur are thus plainly accounted for, especially in view of the abundance and universal occurrence of appropriate larval food.

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[a] Circular No. 71, U. S. Dept. Agriculture, Bureau of Entomology.
[b] Idem, p. 3.

Howard says that people living in agricultural communities will probably never be rid of the pest, but that in cities, with better methods of disposal of garbage and with the lessening of the numbers of horses and horse stables due to the advent of automobiles and electric street railways, the time may come when window screens may be discarded. The prompt gathering of horse manure, which may be variously treated or kept in a specially prepared receptacle, would greatly abate the nuisance, and city ordinances compelling horse owners to follow some such course are desirable.

During the summer of 1897 a series of experiments was carried out by Howard with the intention of showing whether it would be possible to treat a manure pile in such a way as to stop the breeding of flies. It was found to be impracticable to use air-slacked lime, land plaster, or gas lime with good results. Few or no larvæ were killed by a thorough mixing of the manure with either of these substances. Chloride of lime, however, was found to be an excellent maggot killer. Where 1 pound of chloride of lime was mixed with 8 quarts of horse manure, 90 per cent of the maggots were killed in less than twenty-four hours. However, chloride of lime costs at least 3½ cents a pound in large quantities, so that frequent treatment of a large manure pile with this substance would be out of the question in actual practice.

Kerosene was also tested. Hundreds of thousands of flies were destroyed by its use in the experiments, but it was found far from perfect, since if used at an economical rate the kerosene could not be made to penetrate through the whole pile, so that a considerable portion of the house-fly larvæ in the manure escaped injury in this treatment, which was found to be so laborious that hardly anyone could be induced to adopt it.

The most efficient preventive measure was found to be the preparation of a special receptacle for the manure, which was very readily accomplished. A closet was built in a corner of the stable nearest the manure pile. It had a door opening into the stable proper and also a window. A door was built in the outside wall of this closet and the hostlers were directed to abolish the outside manure pile, and in future to throw all the manure collected each morning into this closet, the window of which was furnished with a wire screen. A barrel of chloride of lime was put in the corner of the closet. Since that time every morning the manure of the stable is thrown into the closet and a small shovelful of chloride of lime is scattered over it. At the expiration of ten days or two weeks the gardeners open the outside door, shovel the manure into a cart, and carry it off to be thrown upon the grounds. This treatment has proved very successful at the stable of the United States Department of Agriculture.

The experiments described above have reference only to the prevention of the breeding of flies in horse manure. Somewhat different measures are necessary to prevent them from breeding in human excrement. The box privy is always a nuisance from any point of view, and is undoubtedly dangerous as a breeder of flies. Hence box privies should not be permitted to exist unless they are conducted on the earth-closet principle. With a proper vault or other receptacle, closed except from above, the breeding of house flies can be prevented. Covering the refuse with lime, however, is more certain than the use of earth. The privy-vault nuisance is a real one, and no community can hope to stamp out typhoid entirely without either exercising the most unremitting, rigid supervision of the latrines or abolishing them altogether.

Wind may also affect the distribution of infected feces. Cases are on record where pits have been dug for the accommodation of considerable numbers, such as soldiers in camp, and the material has become dried and been blown by a violent wind into food which was exposed. Perhaps at the same time persons were infected by inhaling the swirling dust through the mouth.

It is known that typhoid is distributed by vegetables commonly eaten raw, which have been cultivated with contaminated night soil. Often infected privy vault or cesspool matter is used as a fertilizer with disastrous results. An epidemic of typhoid fever in a Massachusetts institution was traced to the use of celery which was enriched with manure which was known to contain enteric feces.

About the 1st of August, 1892, there appeared at Springfield, Mass., a typhoid-fever epidemic that was confined to the customers of one milkman, who, it was found, purchased his milk from several dairymen. On one of these farms had occurred a case of "bilious typhoid fever" and others of the household had been obliged to go to bed with "slow fever." The stools of the patients went into the privy, it is believed, without disinfection. It was the practice on this place to cool the milk by submerging the cans in a well in such a manner that they rested on the bottom and were covered by 2 to 4 feet of water. As the stoppers leaked, it followed that if the water was polluted with typhoid germs the milk would become infected. It was at first difficult to account for the pollution of the water, for the well was at some distance from the house and the water was not used therein. However, the construction of the well, which was an ordinary dug one of unusually large diameter, admitted of its being readily polluted from the top. The mouth was covered with a platform of old and badly worn planks, loosely laid on, with rounded edges bordering on wide cracks. Furthermore, the planks were separate in order that they might be readily lifted to put the milk in the well to cool. The spout of the pump overhung the platform, so that

eless pumping easily washed matter on the planks through the le cracks into the well. Lumps of manure, evidently from the ty boots of men, were on the platform, and it was found that linary stepping about upon the boards shook this dung into the ll and also that a little pumping washed it in. Shortly before the phoid fever broke out in Springfield, the contents of the privy ult before mentioned were spread upon a tobacco field, and from is field the laborers frequently passed to get water and to work out the milk. Thus fecal matter originally from the privy clung to eir boots as they worked in the field and was scraped off and shaken to the well as the men performed their duties about it. So the well ater and milk were polluted and the epidemic was established.[a]

Milk is a medium in which the typhoid bacillus multiplies with eat rapidity and contaminated milk supplies have repeatedly propgated the disease. The infection is usually brought about by a se of "walking typhoid" (i. e., where the patient is not confined to s bed) in the dairy, or the washing of the utensils or adulteration the milk with polluted water. The infective matter is circulated out a dairy with such facility that the milk ordinances of cities rbid in the most positive terms the delivery of milk from farms here the disease exists.

In late years it has been discovered that shellfish, such as oysters d clams, which live in sewage-polluted water are apt to convey phoid. Several occurrences of the disease have been found to be e to this cause. This source of typhoid should arouse the solicide not only of sanitarians but also of fish dealers, clam diggers, d oyster dredgers, who have a right to demand protection in their siness.

While all these factors according to circumstances play a more or s important rôle in the dissemination of typhoid, it is generally cognized that impure water is the principal agent in the transmison of the disease. Every one of the bad epidemics has been indutably traced back to polluted water, and there is not a State in the nion or a country in the world that does not pay its monthly toll lives to contaminated water.

Augusta, Me.; Lowell, Lawrence, and Newburyport, Mass.; New aven, Conn.; Ithaca, N. Y.; Butler, Plymouth, and Pittsburg, Pa.; mberland, Md.; Ashland, Wis.; Chicago, Ill.; Washington, D. C., d many other places have passed through the ordeal of a waterrne typhoid epidemic. The supplies are always contaminated by introduction of infected feces, usually suddenly, but sometimes for nsiderable lengths of time. Typhoid-fever epidemics due to impure ter are characterized by being very limited or very widespread, cording to whether the water is used by few or many. The former

[a] Sedgwick, W. T., Ann. Rept. Massachusetts State Board of Health, 1892.

type pertains to well waters and the latter to city supplies of considerable size. In many well-water epidemics it is possible to draw a circle of short radius, with the well for a center, which includes nearly all of the cases. That is, the victims are among those who habitually use the well. The onset of such epidemics is usually sudden, their period of extreme virulence is brief, and they have a tendency to disappear.

When large supplies are infected the cases are distributed throughout the community and appear either in a desultory fashion, as the result of slight pollution, very likely at different times and places, or in great numbers at one time, owing to the sudden introduction of a large quantity of pollution, which is usually effected by heavy rains or rapid thaws. In the case of epidemics from large supplies the period of malignancy is somewhat less sharply marked than in well-water outbreaks, but the proclivity to die out is as noticeable.

This tendency of epidemics to run out brings us to a consideration of the typhoid bacillus itself, for it is manifest that if this organism is the cause of the disease something must have happened to it or the outbreak would continue indefinitely. At the outset it must be frankly admitted that we have not so certain a knowledge of the history of the bacillus in water as is desirable. Great ingenuity and much work have been spent in the effort to determine the longevity of the typhoid bacillus in water. The difficulty has been to reproduce in experiments the conditions that surround the germ in flowing streams, wells, and reservoirs. Such environments appear to have been most nearly approximated in the methods introduced by Jordan and Zeit[a] and developed by Russell and Fuller.[b] The results of the latter investigations are as a whole concordant with those of the former, and show that the typhoid bacillus lives five days in sewage and eight to ten in water. They indicate also that the life of the bacilli is shorter when they are in direct contact with sewage bacteria than it is when they are exposed in sewage but protected from the bacteria therein. The experiments are so perfect that it seems justifiable to assume a life of ten days for the typhoid bacillus in water, but great caution should be exercised in generalizing further, though the results may tempt one to infer that the existence of the germ is but little, if at all, prolonged beyond the maximum period observed in the experiments. Whipple and Mayer[c] have by experiments suggested that the amount of oxygen dissolved in the water may have an important influence on the longevity of the typhoid bacillus and query whether the rapid disappearance of the germ in sewage is not in part due to the absence of this element. It seems to be the prevalent belief that the various mineral salts commonly held in solution by natural waters neither

[a] Jour. Infectious Diseases, vol 1, no. 4; Engineering Record, December 24, 1904.
[b] Reports and Papers, Am. Pub. Health Assoc., vol. 21, pt. 2, p. 40.
[c] Reports and Papers, Am. Pub. Health Assoc., vol. 21, pt. 2, p. 76.

ror nor inhibit the growth of the typhoid organism. The litera-
re on this subject appears to be scanty, and it is suggested that here
a field for investigation. Thus it appears that before definite opin-
is as to the longevity of the typhoid bacillus can be formulated it
ll be necessary to prosecute every feasible bacteriological experi-
nt and to carefully collate and study the facts gleaned from inquir-
into epidemics.

Although the science of bacteriology has not determined the length
life of the typhoid bacillus in water, it has adduced certain facts in
gard to bacteria in general that it seems reasonable to suppose apply
that germ. These are:

1. That all bacteria multiply rapidly in their natural habitat, and
nversely that multiplication is checked elsewhere.
2. That an abundant food supply and an optimum temperature are
ime factors in bacterial development.
3. That insolation has an injurious effect on bacteria.
4. That they are slightly heavier than water and so tend to sink in it.
5. That certain microscopic organisms, namely, algæ and infusoria,
d on them and so reduce their numbers.

The typhoid bacillus thrives best in the human intestine, where
d is abundant and the temperature is high, so that its invironment
comes unfavorable when it is brought into water. There it has to
mpete for food with the bacteria that live in that element. The low
nperature, the sunlight, the tendency to sink, and microscopic
ganisms all work to exterminate it. These are the natural factors
at kill the germ and end epidemics without the intervention of
man aid.

In regard to the temperature of rivers, it is to be regretted that no
asurements are available, nor have any very extended observa-
ns been made on any American river with a delicate instrument,
ch as the thermophone. Kofoid,[a] however, did some careful work
th thermometers on Illinois River from August, 1892, to March,
99. According to his observations, the temperature of river water
llows an annual cycle of the same general character year after year,
th ever present minor variations of local origin. In winter the
ater is coldest and varies least in temperature; the minimum
served was 32° F., the average was 32.75°, and the maximum was
rely higher than 34°. This constancy is doubtless due to the ice
hich normally covers the stream and especially its backwaters.
hen the temperature is below 39.2° F., the point of greatest density
water, the colder waters are at the surface, though there is usually
ry little difference of temperature at different levels during this
ason. In spring the temperature of the water commences to rise

[a] Kofoid, C. A., Bull. Illinois State Lab. Nat. Hist., vol. 6, 1903, pp. 168 et seq.

very early, the beginning and rate of increase depending on the peculiarities of individual years; the observations made indicate a gradual increase from an average of 40.45° F. in March to 60.46 ° in April and to 68.27° in May, which is a month not only of marked rise but also of considerable fluctuation in temperature. In summer the water is warmest and varies greatly in temperature; the average maximum rose from 77.75° in June to 81.49° in August and fell to 74.21° in September. The average fluctuation during this season was less than 10° F., though the absolute range for August in five years was from 74.3° to 89°. These rises and falls, combined with the effects of the wind and diurnal changes in temperature, cause considerable vertical circulation of the water, because the surface waters, especially on still hot days, are from a fraction of a degree to 5° warmer than the deeper waters. In autumn the fall of temperature begins late in September and becomes practically complete in November; like the rise in spring, it is subject to irregularities in its rate and permanence. The maximum and minimum observed in the river during this season were respectively 96° and 32° F. When the temperature of the air falls in autumn below that of the water the consequent convection of the surface and bottom layers of the river causes the water temperature to become practically uniform at all points in the vertical section. These well-defined periods of minimum, increasing, maximum, and decreasing temperature doubtless cause in the minute organisms in the water corresponding seasonal changes as fundamental and as extensive as those that affect the plant and the animal life of aerial environment.

In addition to the influence of season there are several minor causes of variation in temperature, such as the entrance of water from tributary streams, springs, and impounded backwaters, the local shallowness of the water, and the diurnal range of temperature in the air. The changes produced by the entrance of water are of course individual and variable. The depth of the stream determines the effect of the temperature of the bed, though the difference between the surface and bottom temperatures of stream water is, as a rule, very small. The daily variations in temperature depend essentially on those of the air. On August 5, 1898, the temperature of the water near the surface varied from 79.5° F. at 5 p. m. to 74° at 2 a. m., while that of the water near the bottom (depth 8 feet) varied from 74° at 8 a. m. to 76° at 11 a. m., a fluctuation of only 2° F.

Some of the conclusions reached by Kofoid are particularly pertinent to the relation of river temperature to typhoid fever. The average temperature of Illinois River in August was 81.49° F., only 16.7° below body temperature, and the maximum observed in that month was 89° F., only 9.2° below body temperature. Accordingly it would appear that at times the bacillus of typhoid fever may be in

ater at a temperature not far from the optimum. The fact that in mmer the temperature causes a vertical circulation in the river ter should be borne in mind in deciding on the efficacy of sedimen- tion in removing bacteria. The fact that the seasonal variations temperature cause corresponding variations in the vitality of ero-organisms indicates that decrease of heat is of unequal moment different seasons of the year in destroying bacterial life. Finally, would be interesting to know whether, on account of the small dif- rence noted between surface and bottom temperatures, it is ever ssible for sewage to flow a considerable distance in a river without ixing with the stream water. If it is, then sewage might in some ses flow from one city to another and arrive in a fairly concentrated ndition.

With regard to the Potomac itself, it may be remarked that the rge quantity of water received from ground flow from mountain ibutaries and from mines all tend to influence its temperature.

The destruction of food material in rivers apparently bears an inti- ate relation to temperature, as was shown by investigations on llinois River and the Chicago drainage canal between Bridgeport nd Joliet. "Ordinarily in the warm weather there is a marked oxida- ion here with evident destruction of organic matter. This was hown in the investigations of 1888 and in striking degree in those of he summer of 1886. In the cold winter and spring months of 1889, n the contrary, the oxidation was slight between Bridgeport and oliet, and this is probably the normal low-temperature condition."[a]

It is an interesting fact that the period of minimum temperature, s defined by Kofoid, coincides with the months of the minimum revalence of typhoid fever in Washington, and that the influence of he period of maximum temperature extends over all the months uring which the disease is at its height except only the second half f October. If it be admitted that by reason of the geographic situa- on of the Potomac basin the temperature of the stream remains at ie maximum a few weeks longer than it does in Illinois River, ie months of the maximum occurrence of the disease fall quite ithin the period of maximum temperature. Furthermore, the ecline of typhoid fever in autumn seems to coincide very closely ith the fall of temperature, and the increase of typhoid fever that cceeds its period of minimum prevalence seems to occur near the nd of the period of increase of temperature. This apparently indi- ates that it is necessary for the water to attain a rather high temper- ture before it reaches its most favorable condition for transporting ie germs of typhoid fever. It is true that it has not been uncommon or water-borne epidemics of the disease to occur in early spring and

[a] Egan, J. A., Pollution of the Illinois River: Sanitary Investigations of the Illinois River and its tributaries, Illinois State Board of Health. 1901, p. xxiii.

also in early winter. However, it is believed that in these cases the time that elapsed between the introduction of infected feces into the water and the lodgment of the bacilli in their victims was brief, and that therefore the germs were able to withstand untoward temperature conditions to which they would have succumbed had the interval of exposure been longer.

It should be remembered that, as Kofoid has determined, the temperature of a river responds very quickly to fluctuations in the temperature of the air above it. Sedgwick and Winslow[a] have pointed out that "in communities with reasonably pure water supplies the typhoid fever follows the curve of seasonal temperature with extraordinary regularity. If the monthly deaths from the disease be plotted and compared with the monthly temperatures, it will be found that the curves are almost parallel, the typhoid rising with the temperature after about two months, an interval representing the incubation period of the disease and the time which elapses before death." So, in a measure, these river-temperature periods but reflect typhoid conditions which prevail under like temperature conditions on land; and it is felt that the river temperatures act in the same direction as the air temperatures and play a considerable part in fostering or restraining the dissemination of the disease. In this connection the statement made by Clark and Gage[b] that in a river as polluted as the Merrimac the numbers of *Bacillus coli*, the common intestinal bacillus, are more numerous in warm than in cold weather is possibly significant.

How much importance should be attributed to microscopic organisms in reducing the bacteria in water is a moot question. There seems to be a concurrence of opinion that they play only a minor part, but the matter will have to be investigated more carefully than it has been before the possibility of their having a considerable beneficial influence in this direction can be positively denied. However, it is certain that at some seasons of the year they are present in the water in very small numbers and therefore that their action is not constant.

As water is not the normal habitat of typhoid bacilli, it is universally admitted that their detention in that medium is of the utmost importance in their elimination. By giving the factors of insolation, unfavorable temperature, and reduction of their food supply an opportunity to act through considerable time the vitality of the germ is reduced and its final destruction is brought about. The quicker the journey from intestine to intestine is accomplished the better is the chance for the survival of the bacillus. Now, sedimentation is recognized as potent in delaying the germ in its travels.[c] The process is

[a] Jour. New England Waterworks Assoc., vol. 20, No. 1, 1906, p. 59.
[b] Rept. Massachusetts State Board of Health, 1892, p. 279.
[c] Whipple, G. C., The Microscopy of Drinking Water, 1899.

a simple one in reservoirs and lakes, for it is interfered with only by the convectional currents established by the heating of the water and by the very considerable circulation of the water brought about by the wind. But in rivers it is further complicated by the phenomena of transportation.[a] Everyone knows that the solid material brought to a river by various agencies does not sink to the bottom as soon as it reaches the stream, but is carried forward by the current. By careful experimentation some of the laws that govern this action have been discovered. It is well known that the power of flowing water to transport débris increases with increasing velocity, and that the size, specific gravity, and form of the loose material determine whether or not it will be moved by a current of given velocity. The smaller the divisions of any mass the larger the ratio of surface to weight, and the force which a current of given velocity exerts against objects in its path varies as the area of the opposing surface. Therefore the finer the particles the more easily will they be transported. But the ability of streams to carry débris in suspension is dependent not only on these factors but on the presence of secondary and especially of upward currents, which tend to lift up the particles brought within their influence. Were it not for these minor currents particles would sink in a regular curve, whereas the path actually traveled by them is a very broken line, sometimes tending toward the bottom, at others toward the banks of the stream, and again upward toward the surface. When the particles finally reach the bottom they remain there only so long as they do not come within the influence of a current strong enough to lift them into circulation, which may be for either a long or a short period. It has been found that the change in the velocity of streams in horizontal planes is greatest near the shore and least near the thread of maximum current; and that in vertical planes it is greatest near the bottom and surface and least at about one-third of the depth of the stream—that is, where the absolute velocity is greatest. If, then, the water be either charged to its maximum capacity or overcharged with sediment, the highest percentage of material will be found near the banks, surface, and bottom, and the least amount at a depth of about one-third that of the stream. If, however, the water is undercharged with suspended material, as is the case with most streams, the distribution will not follow any law, the amount at any locality being dependent on the chance swirls and boils. It is an important fact that the transporting power of running water increases in a greater ratio than the increase in velocity. It has been found that if the surface of an object remains constant the force of a current striking it varies as the square of its velocity; also that the transporting power of a current, or the weight of the largest fragment it can carry,

[a] Russell, Rivers of North America.

varies as the sixth power of the velocity. It will be seen that under this law doubling the velocity of a current increases its transporting power 64 times. An increase in the volume of a stream increases its velocity; hence floods multiply the transporting power of water and by so doing acquire a destructive power which is accounted for by the foregoing law.

Besides the material which a stream carries in suspension, there is that finely divided matter which it rolls along over its bed. This does not travel in sheets, but moves along in wave-like forms which have a long, gentle slope in the direction of the current and an abrupt drop on the downstream end. Thus particles which reach the bottom of a stream do not come to rest unless they are too heavy for the stream to drag along.

From this discussion it is evident that sedimentation is profoundly affected by any factor which tends to quicken or retard stream flow, and that it is exceedingly difficult to follow material after it is once committed to a stream. At one time it will be in suspension, at another at rest. Now it may travel near the bottom, again at the surface, or at another time it may be deflected against the banks of the river. But it is evident that all these migrations take time, and this is what is desired to accomplish bacterial purification. Thus food material may become exhausted before it has traveled far downstream, or some other agent may have worked considerable change in a few miles of river flow.

It should be noted that sedimentation means more than the mere settling out of bacteria by their own weight, for other and heavier materials in sinking mechanically entrain the germs and drag them toward the bottom. This action is most effective when large quantities of silt are being rapidly deposited—that is, when the action is taking place in turbid waters. In relatively clear water it loses much of its importance.

Rapid sedimentation is often brought about by chemical means. Thus, when highly acid mine waters are discharged into rivers whose waters contain notable amounts of lime, insoluble salts are formed, which sink rapidly to the bottom. As they do so they carry a large proportion of the bacteria with them, so that mine wastes are not always an unmixed evil.

Though the Potomac is as a whole a swift river, sedimentation is undoubtedly active in much of its course. Even in its upper reaches this force is at work, as anyone can test for himself by walking along the banks from Westernport to Keyser, where large quantities of salts resulting from the action of the waters of Georges Creek on the limy wastes of the West Virginia Pulp and Paper Company have been deposited on the rocks and in the shallows. In the many pools in the bed of the river the current must necessarily be checked and deposition

elerated. Particularly important are the seven dams, which cause ck water for miles. In low stages of the river the water must move ward the dams very slowly, and they undoubtedly afford the forces purification by deposition the greatest play. Some question has en raised whether the protection against typhoid accorded in this y does not contain an element of danger. Thus Sedgwick has ted that in Lowell and Lawrence, Mass., the summer typhoid curred after sudden rises in Merrimac River caused by thunder-rms and the like, and has suggested that the increase of the disease ght be partly accounted for by the fact that considerable infected terial had collected behind the dams on the river and had been car-d downstream when the water flowed over the dams in considerable antities.

This raises the important question as to what becomes of germs er they are deposited at the bottom of streams. If they simply t there until they are again brought into circulation by the scour-; of the beds in floods and by other forces, much more importance s been attached to sedimentation than it deserves. But it would m that the environment of the bottom of a stream must be hostile germs which live in the human body. Jordan has pointed out t a careful examination of the bed of Illinois River failed to reveal y accumulation of sludge from the large amounts of sewage it eives, and therefore it may be concluded that the amount of avail-le food material for bacteria at the bottom of streams can not be y great. It is conceivable that the sewer of a small village might made to discharge into a pool of a stream, instead of into the cur-nt, and so convert the pool in times of low water into a place favor-le for the multiplication of germs, which would be carried into culation by a sudden flood, with disastrous results. But these tors are not generally considered of serious import as affecting the lief that sedimentation is one of the most powerful factors in purify-g water. Rather, it is held that they operate only under special nditions, at rare intervals, if at all. However, the sediment of wage-polluted streams would undoubtedly be a fruitful field of vestigation.

There has been much quibbling over the question whether the ution of a severely polluted stream with the waters of a pure one ould be considered as purification or not. It would seem that the sult achieved is clear—namely, the chance of drinking typhoid rms has been lessened. In that sense there has been purification, t it does not necessarily mean that there has been any destruction food material nor that any germs have been killed.

The deaths from typhoid fever in the principal cities of the world e shown in the following table:

Population, total deaths, and deaths from typhoid in the principal cities of the world, 1880–1904.[a]

Year.	New York (old city).			Brooklyn.			Boston.			St. Louis.			Chicago.			Philadelphia.			Washington.		
	Population.	Total deaths	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.
1880....	1,209,268	31,937	372	.....	.....	.....	368,839	8,531	154	.....	.....	.....	503,298	10,462	.....	846,980	17,711	498	183,060	4,075	95
1881....	1,246,011	38,624	594	.....	.....	.....	368,190	9,016	207	.....	.....	.....	540,000	13,874	.....	868,000	19,515	645	188,653	4,430	153
1882....	1,283,870	37,924	516	.....	.....	.....	373,623	8,995	212	.....	.....	.....	560,639	13,234	.....	886,539	20,059	650	191,980	4,223	123
1883....	1,322,880	34,011	625	.....	.....	.....	379,129	9,740	198	.....	.....	.....	580,000	11,555	.....	907,041	20,076	579	196,490	4,558	118
1884....	1,363,075	35,044	476	.....	.....	.....	384,270	9,622	216	.....	.....	.....	630,000	12,471	.....	927,995	19,999	662	201,110	4,841	153
1885....	1,404,401	35,682	405	687,000	15,369	153	390,393	9,618	152	400,000	7,490	125	665,000	12,474	496	949,432	21,392	610	205,840	4,982	134
1886....	1,447,166	37,351	433	747,000	15,790	123	401,374	9,268	135	.....	8,268	124	704,000	13,699	483	971,363	20,005	618	210,680	4,728	151
1887....	1,491,137	38,933	421	778,800	17,079	143	412,663	10,073	183	.....	9,155	116	760,000	15,400	381	993,801	21,719	621	215,630	4,694	167
1888....	1,536,444	40,175	364	810,000	18,061	153	424,274	10,197	170	.....	9,015	130	830,000	15,772	375	1,016,758	20,372	785	222,830	5,225	188
1889....	1,583,120	39,679	397	842,000	18,480	161	436,208	10,259	186	.....	8,004	146	1,106,000	16,946	453	1,040,245	20,536	736	232,460	5,158	213
1890....	1,631,232	40,103	352	875,000	19,827	182	448,477	10,181	155	452,000	8,409	140	1,200,000	21,869	1,008	1,046,904	21,732	666	242,520	5,534	257
1891....	1,680,796	43,659	384	910,000	21,349	180	457,772	10,571	154	.....	9,530	165	1,250,000	27,754	1,997	1,039,264	23,367	684	253,010	6,103	186
1892....	1,708,124	44,317	399	898,256	20,807	162	467,260	11,236	137	.....	10,225	441	1,438,000	26,219	1,499	1,092,168	24,305	539	260,800	6,416	216
1893....	1,758,010	44,479	381	928,408	21,017	179	476,945	11,710	148	.....	10,303	215	1,600,000	27,095	670	1,115,562	23,655	456	265,600	6,119	202
1894....	1,809,353	41,175	326	959,572	21,183	158	486,830	11,529	141	.....	8,710	171	1,567,727	23,701	491	1,139,457	22,680	369	270,514	5,899	228
1895....	1,873,201	43,420	322	991,782	22,568	173	501,083	11,329	163	.....	9,425	107	1,600,000	24,319	518	1,163,864	23,797	469	272,337	5,782	235
1896....	1,906,139	41,622	297	1,025,074	22,497	163	516,305	11,634	162	.....	9,897	108	1,619,226	23,262	751	1,188,793	23,982	402	275,562	5,832	148
1897....	1,940,553	38,887	299	1,060,483	20,674	173	528,912	11,154	173	.....	9,554	123	1,619,226	21,809	437	1,214,256	22,735	401	277,782	5,486	130
1898....	1,976,572	40,438	376	1,095,047	21,856	267	541,827	10,866	185	.....	8,908	95	1,650,000	22,747	636	1,240,266	22,790	639	283,100	5,815	191
1899....	2,014,330	39,911	294	1,131,805	21,649	205	555,057	11,167	165	.....	10,024	131	1,950,000	25,503	442	1,266,832	23,796	948	288,500	5,863	199
1900....	2,053,979	43,227	372	1,169,796	23,057	301	560,892	11,678	143	575,000	9,849	148	1,698,575	24,491	337	1,293,697	25,078	449	294,000	6,059	220
1901....	2,095,686	43,307	412	1,209,064	23,271	274	573,579	11,300	142	598,000	10,001	176	1,758,025	24,406	509	1,321,408	24,137	444	299,000	6,050	172
1902....	2,139,632	41,704	400	1,249,650	22,344	322	584,553	10,983	139	621,000	10,353	222	1,820,000	26,455	801	1,349,712	23,847	588	305,400	5,788	226
1903....	2,186,017	41,776	350	1,291,597	22,192	267	600,929	10,632	119	645,000	11,145	288	1,885,000	28,923	588	1,378,624	25,947	957	311,300	5,944	140
1904....	2,235,060	48,743	309	1,334,952	24,831	303	614,522	10,757	135	685,000	11,506	225	1,932,315	26,302	373	1,408,154	25,972	744	317,200	6,221	135

[a] Rept. Boston Health Dept., 1904.

Year.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.	Population.	Total deaths.	Typhoid deaths.
1880		55,706	2,003	1,123,749	32,823	527	721,016	20,453	171	3,771,139	81,832	702			
1881	2,239,938	55,103	1,955	1,158,530	31,055	352	741,208	21,549	171	3,824,980	81,071	977			
1882		56,854	3,214	1,198,205	30,445	357	749,919	21,595	187	3,861,876	82,905	975	511,415	12,909	166
1883		54,763	1,980	1,232,716	35,056	222	750,762	21,194	157	3,901,194	80,578	935		12,985	162
1884		55,050	1,503	1,271,677	32,832	243	759,849	20,353	95	3,939,832	83,050	936		14,476	167
1885		52,726	1,320	1,315,656	31,483	214	769,889	21,976	106	3,978,883	80,000	585		13,839	184
1886	2,260,945	55,110	954	1,363,031	34,203	181	780,006	20,869	85	4,018,321	82,276	618	541,031	14,382	112
1887		52,856	1,385	1,415,260	30,336	193	790,381	20,459	80	4,058,150	82,304	612	537,548	13,764	95
1888		51,230	756	1,472,151	29,208	188	800,836	20,349	107	4,098,374	79,099	694	534,068	13,919	140
1889		54,083	1,008	1,528,721	34,460	290	811,434	20,106	103	4,138,996	76,026	528	530,040	14,006	130
1890		54,566	695	1,579,524	33,393	143	822,176	20,324	77	4,180,021	80,554	618	527,223	12,159	123
1891	2,424,705	54,443	549	1,601,327		166	1,378,530	34,479	85	4,221,452	90,216	547	523,838	13,047	167
1892		54,536	691	1,656,715	32,696	137	1,406,633	35,134	116	4,263,294	87,749	436	520,426	14,283	99
1893		52,955	570	1,714,938	36,032	161	1,435,931	34,515	105	4,306,411	91,536	719	517,145	13,911	92
1894		49,205	697	1,655,235	30,961	69	1,465,637	33,994	74	4,349,166	77,039	635	513,818	12,671	111
1895		51,451	274	1,677,304	33,627	95	1,495,764	34,879	86	4,392,346	86,937	614	510,514	13,919	221
1896	2,511,629	47,920	262	1,695,313	30,578	80	1,526,623	34,132	79	4,421,955	83,511	591	507,220	12,073	246
1897		46,988	249	1,738,885	30,622	71	1,551,129	33,187	84	4,463,189	80,944	583	638,291	16,215	192
1898		49,574	256	1,805,054	30,571	78	1,580,295	32,356	93	4,504,766	83,936	585	632,512	14,617	206
1899		50,511	754	1,817,952	34,011	74	1,623,134	33,333	66	4,506,752	89,689	801	644,120	15,590	145
1900		51,725	912	1,864,203	35,409	109	1,656,662	34,303	137	4,598,129	86,007	756	668,645	15,380	148
1901	2,660,494	50,195	363	1,891,900	34,091	88	1,691,996	33,502	76	4,544,383	79,924	548	668,645	16,269	174
1902	2,660,559	49,275	17	1,920,459	30,737	52	1,726,604	33,857	51	4,579,110	82,540	585	686,322	15,493	154
1903		46,557	280	1,955,875	31,879	63	1,744,177	33,172	68	4,613,812	72,019	396	710,337	15,392	190
1904		47,354	334	2,040,455	31,557	75	1,797,992	32,931	60	4,649,038	76,694	297	716,810	14,210	108
													723,430	15,851	82
													761,712		
													775,601	15,054	210
													786,807	14,483	110
													796,357	14,794	142
															84

TYPHOID FEVER AT WASHINGTON, CUMBERLAND, AND MOUNT SAVAGE.

When this inquiry was begun a thorough investigation of the typhoid-fever mortality was contemplated, for the ravages of this disease are in general caused by the contamination of water supplies by privies, cesspools, and sewers, and it was thought that no better measure of financial loss through river pollution could be had than the destruction of human life it caused. But it was discovered that none of the four States in which the basin lies had registration laws. Accordingly this study had to be confined to the District of Columbia, where the records extend over thirty-one years. The law has been administered with great fidelity by the health department, which has assembled the results with intelligence and discrimination. It is to be regretted that the statistics do not cover the entire period through which the Potomac has been the water supply of Washington, but they were not collected from the troublous times of the civil war until August, 1874. Effective registration really began in January, 1875, and only from that date on are the results of value. Recently Pennsylvania has enacted an excellent registration law and Maryland has adopted one which it is hoped may prove serviceable, but Virginia and West Virginia have none. This is to be regretted, for the faithful registration of births and deaths more than repays its cost by the aid it gives in establishing property rights and in suppressing child murder. Moreover, by the lack of vital statistics sanitary science is deprived of a great help in the fight against communicable disease. Unless the health of a community is a matter of knowledge, of record, and not of hearsay, it is impossible to tell whether its condition is normal or whether its water supply, its milk supply, or some other function is deranged and diseased. It is to be sincerely hoped that this defect will soon be cured by wise legislation.

At Washington the undue prevalence of typhoid fever has been caused by the public water supply, which has been taken from Potomac River since December, 1863, and which was consumed without purification until October 5, 1905.

Some of the other factors which have been mentioned as producing typhoid undoubtedly are responsible for a part of the cases. There are many privies in the city, and they have in all probability been at times foci from which contagion spread. There are polluted wells which must have played their part. Cases of auto-infection were probably numerous. Small epidemics caused by infected milk have been traced to their sources, and the disease has been brought in from outside. But the typhoid has been too constant and too generally distributed in the city to lay more than a small part of it to the door of these sporadic outbreaks. It can be accounted for only by

a impure water supply, and it now remains to consider what scope
ıe natural and artificial forces at work on the Potomac give to the
veral factors that favor or militate against bacterial life. Food
ıpply for the germs must be plentiful, being furnished by the
ımerous sewers and privies that discharge into the river, the dis-
llery wastes, the rinse water from the finished goods of several
ctories, and most of the organic wastes received by the stream.
he action of sunlight is regarded as only mildly inhibitory, but it
as full play on the Potomac, for the water is light colored and is
ear except during rather short periods of freshets. Moreover,
ıuch of the river is shallow, so that the light rays penetrate quite to
ıe bottom over considerable stretches.

In the early days of Washington the feasibility of supplying the
ity with water from the Potomac was considered, but it was not till
859 that water was turned into the aqueduct. It came from Dale-
arlia Reservoir, then wholly supplied by Little Falls Branch. This
eservoir was built with the idea of affording an opportunity for
larification of the water by sedimentation as it passed through.
he same year the distributing reservoir in Georgetown was built.
ı the early days these reservoirs may have afforded considerable
otection, but with the present daily consumption of 65,000,000
llons the former gives a storage of only sixteen hours and the latter
only twenty-three hours. In 1902 the Washington city reservoir
as put in use and gives an additional storage of forty-five hours.
. December, 1863, water from the Potomac at Great Falls, 14 miles
›ove Washington, was received, and it has been the main supply of
e city ever since. As there were no vital statistics kept at that
ne, it is impossible to say what effect the introduction of the sup-
y had on the public health. Indeed, had such records been kept
ieir interpretation would demand great caution, for it was at the
ne of the civil war and the soldiers of both armies suffered terribly
om typhoid, as may be seen from the subjoined figures taken from
ıe Medical and Surgical History of the War of the Rebellion. The
gures do not include typhoid malaria, and it is to be remembered
ıat the troops did not operate in the Potomac basin all the time.
he table does not include all the troops operating in the basin, and
›me of the cases were of men who belonged to the armies cited, but
ho were temporarily detached therefrom at the time of sickness.
lowever, the figures it is believed give an idea of the prevalence of
ıe disease, which is all that is desired. The armies of the Confed-
:acy are believed to have suffered more heavily than did those of
ıe Union.

Typhoid fever in Federal Army during civil war.

Date.	Army of the Potomac.		Department of Shenandoah.		Department of Western Virginia.		Middle division.	
	Cases.	Deaths.	Cases.	Deaths.	Cases.	Deaths.	Cases.	Deaths.
July, 1861–June, 1862	8,228	917	735	84	2,766	232	.....	.....
July, 1862–June, 1863	8,442	1,323	.....	.....	655	79	.....	.....
July, 1863–June, 1864	1,693	220	.....	.....	812	83	.....	.....
July, 1864–June, 1865	.....	.....	.....	.....	.....	.....	819	.....

It is evident that the whole Potomac drainage area was thoroughly seeded with typhoid during the war.

Other events have had an intimate relation to the prevalence of typhoid fever in Washington.[a] In 1888 there were many complaints against the character of the water, both on account of its turbidity and its supposed pollution. Accordingly at that time Dalecarlia Reservoir, which was still fed by Little Falls Branch, was cut out of the supply and used only on the rare occasions when repairs to the aqueduct made it necessary. This expedient does not appear to have had any effect on the typhoid death rate of the city. In 1893 it was decided to divert the waters of Little Falls Branch, Mill Creek, and Rock Creek, together with other waters, from Dalecarlia Reservoir, in which they fed. The work was completed May 27, 1895. The typhoid death rate of that year was 53.7, as against 86.3 in 1894. The following year it was still lower, but it rose again in the three succeeding years, yet it never has attained the figures of the years immediately preceding the execution of this work.

There are probably mild outbreaks of typhoid fever at one or more places on the Potomac watershed every year, but two well-marked epidemics are on record which produced decided effects in the District.[b]

The first of these was at Cumberland, Md., and was brought about by typhoid dejecta finding their way into Sulphur Run, which empties into the Potomac somewhat above the water works intake. The trouble began about December 10, 1889, and was not quelled until the beginning of June, 1890. In all 485 cases and 97 deaths of the disease were reported in Cumberland. The river was said to be in middle stage at the time, and soon after the outbreak at Cumberland typhoid appeared at Hancock, 60 miles downstream. Captain Gaillard[c] estimates the time of flow of water from Cumberland to Washington as from four to seven days, but the disease did not appear in unusual measure in Washington until March, 1890. The number of typhoid deaths continued to be abnormally high after this until August, when it was not much above the usual number for the city. The following table gives an idea of the sequence of the disease

[a] Ann. Repts. Chief of Engineers U. S. Army, 1893–1895.
[b] Kober, George, Medical News, April 12, 1890.
[c] Ann. Rept. Chief of Engineers U. S. Army, 1894.

'aths from typhoid fever at Cumberland and Washington, January to July, 1890.

Month.	Deaths.		Month.	Deaths.	
	Cumberland.	Washington.		Cumberland	Washington.
ry	18	11	May	5	13
ary	27	6	June		24
	39	19	July		36
	8	11			

ıe second epidemic which is known to have produced calamitous lts in Washington occurred at Mount Savage, Md., in 1904, and studied by Dr. M. L. Price, whose report, by the courtesy of Dr. ı S. Fulton, secretary of the Maryland State board of health, is e the basis of this account. Mount Savage is situated on Jens Run, about 10 miles west of Cumberland and 185 miles above hington. The town lies at an elevation of about 1,200 feet, on a ntain whose steep sides descend abruptly to Jennings Run and nt Savage Run, both of which flow through the town. The bitants are mostly employees of the Union Mining Company and ıe Cumberland and Piedmont Railroad. They live largely in tene- t houses or rows, boarding houses, and cottages, which are scat- l along the side of the mountain up to an elevation of several lred feet above the streams. The occurrence of house epidemics ng the Union Mining Company's laborers is favored by the general of household furnishings, which makes it necessary for one sil or set of utensils to serve a whole family. In the majority of lies one dipper is used for drinking purposes, water being taken : a common bucket. Cheaply constructed privies are in universal ınd receive very little care, for every heavy rain washes the excess ıcrement into the streams. Jennings Run is at all times grossly ıted by human sewage, and contains a miscellaneous collection of , dead animals, and refuse. The odor during the day is usually ısive, but becomes sweet whenever a heavy rain flushes the run carries its filth into Wills Creek, which in turn delivers it to the ımac. The water of Jennings Run is unpotable, because it is very ily polluted by mine drainage, which contains free sulphuric acid large quantities of iron salts, besides sulphates and carbonates of

ıe water supply of Mount Savage was obtained from 15 private ıgs and 3 artesian wells. After the epidemics broke out several ese were found to be contaminated and were closed by the county d of health. The roundhouse of the railroad company has an ısian well. Only one of its 125 employees had typhoid fever, and certain that he did not confine himself to the company's well. brickyard spring was the only source of water known to have been

specifically polluted by typhoid dejecta, and the victims of the epidemic were confined to those who drank from it.

The outbreak at Mount Savage is interesting, for we have here a story which is probably repeated yearly at one place or another on the Potomac watershed. A number of the wells were polluted by human excreta, no care whatever was given to the privy vaults, and the stream that ran through the town was abominably defiled, yet year after year went by and Mount Savage was not scourged by any pestilence; but the penalty for ignorance and neglect was paid in full when the germs of disease were introduced into the midst of such conditions.

July 4, Mrs. ———, who occupied a small house about 300 feet above the brickyard, on a rather steep incline forming the north bank of Jennings Run, and who had just returned from nursing her brother, a typhoid-fever patient, at Luke, Md., was taken ill with the same

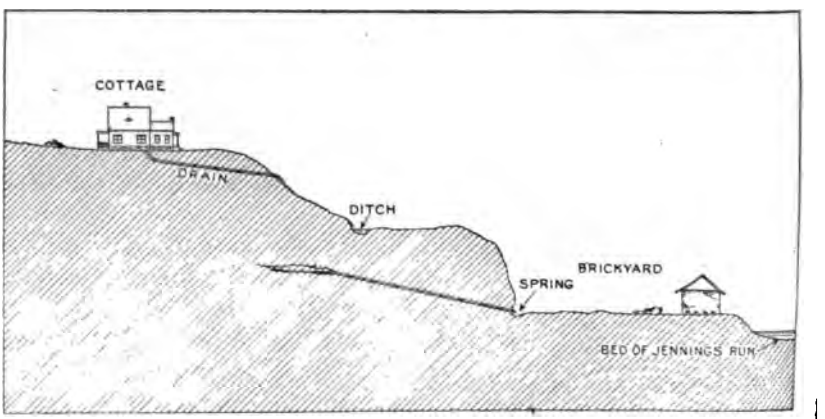


FIG. 2.—Elevation of north bank of Jennings Run, showing course of drainage.

disease. The brother probably contracted the disease in Piedmont, W. Va. Mrs. — —'s infection was evidently contracted at the same place or from her brother. All of the drainage from this house was conveyed through a 4 or 6 inch iron pipe which emerges from the ground and ends 40 or 50 feet below on the side of the hill (fig. 2). This mixed drainage found its way down the hill, a small portion of it reaching an open drain. A road runs along the side of the open drain, over a bank of fire clay above the brickyard. At the bottom of the fire-clay bank, a short distance from the open drain, was a large flowing spring, which furnished an abundant supply of clear water of pleasant taste and appearance and of agreeable coolness. The water was drunk by all of the brickyard employees, about 200 in number. During the early part of July heavy rains occurred, washing surface impurities down the side of the mountain upon which the

—— cottage was located into the spring and Jennings Run. July 11, about one week after Mrs. ———'s arrival, 20 workmen from the brickyard reported to Doctor Murray, the company doctor, complaining of headache, backache, lassitude, and digestive disorders. The strict limitation of these cases to the brickyard employees and the similarity of their symptoms suggested a common source of infection. Accordingly, on the following day, July 12, Doctor Murray posted a notice declaring the water bad and directing the discontinuance of its use. Five additional men reported on this day with typhoid prodromata. From the railroad and other shops supplied with artesian water no cases appeared. The brickyard men were again enjoined against the use of the spring, but a certain number continued to use it during the succeeding twelve or thirteen days. Additional cases were now appearing at the rate of five or six daily, and some of the original cases were showing unmistakable evidences of enteric fever. July 25 Doctor Murray effectually prevented further use of the water by the destruction of the spring, mineral ashes and fire clay being thrown into it till it was buried several feet deep. The chemical and bacteriological reports of water samples drawn by Doctor Murray were received by this time and indicated that the brickyard spring was badly polluted and that other wells and springs in the town were polluted to a greater or less degree. Cases of typhoid fever continued to develop until August 10, sixteen days after the last of the brickyard spring water was drunk. The destruction of this spring by Doctor Murray effectually removed the source of infection and ended the epidemic, but with the arrival of Doctor Price, August 11, other wise measures were taken. The most important of these had for their object the prevention of a secondary epidemic that might be caused by the spreading of contagion from the infected stools broadcast through the community by means of flies. To accomplish this, the privy vaults were thoroughly cleaned through the cooperation of the Union Mining Company, which furnished horses and men to carry on the work. The method adopted was the digging of pits and the burying of the vault contents. Those contaminated springs which could be sealed were closed up and the water of the others was made undrinkable by the use of a harmless emetic, such as copper sulphate or alum. In this work the Allegany County board of health was active, as well as in posting notices requiring the boiling of water, the policing of front yards, and the use of earth ashes or lime in the privies to cover evacuations as soon as they were passed, and in the appointing of district nurses to teach and secure personal prophylaxis in the homes. Disinfectants were used in the stools and urine of the sick. The extermination of the epidemic was due to the effective cooperation of the local physicians, Doctors Murray and Quarles,

with officials of the county and State boards of health. The resul of this epidemic up to August 17 were as follows:

Statistics of typhoid-fever epidemic at Mount Savage, Md., July 4 to August 17, 1904

Total number of cases	1
Bed cases	
"Walking cases"	
Deaths	
Sick August 17	
Convalescent August 17	

By August 22 five more cases had appeared, raising the total to 12 The health department of Washington did not learn of the epidem until August 20, when it sent out warnings to boil the Potomac wat The step was a commendable one, but as the epidemic in Mou Savage was practically over at the time, it was impossible to av the consequences of the early cases. The effect of the epidemic Washington may be seen in the following table:

Typhoid cases and deaths in Washington, D. C., five months of 1902–1904.

Month.	1902.		1903.		1904.	
	Cases.	Deaths.	Cases.	Deaths.	Cases.	Deat
July	130	21	121	17	101	
August	328	39	188	26	226	
September	290	25	138	18	212	
October	247	32	148	19	138	
November	156	19	88	8	104	
Total	1,151	136	683	88	781	

As in 1902 and 1903, the number of cases and deaths made a sudd jump in August, 1904, but the September figures, unlike those of t two other years, remained as high as they were in August. In Octob 1904, there was a quick drop in both cases and deaths, which was n the case in 1902 and 1903. It is evident, therefore, that the specif cause of typhoid fever in Washington in 1904 was discovered an removed. Moreover, the prevalence of the disease was synchronou with that at Mount Savage, which it is known was stamped ou Hence it is concluded that the typhoid at Mount Savage caused th in Washington.

It is interesting to note that the germs at Mount Savage must hav gone pretty directly into the highly acid waters of Jennings Run an then into the acid waters of Wills Creek before reaching the Potoma From this it would seem that mine waters can not be relied on to k the typhoid bacillus. On the other hand it should be remembe that the supply of food material was probably abundant in the init stages of the journey of the germs to Washington, for there are t tanneries on Wills Creek, and the sewage of Cumberland must a have been available.

Another factor which has influenced the degree of prevalence of typhoid fever in Washington is that the cities and towns in the basin have been procuring new and pure water supplies. At many places the information was given during this investigation that typhoid fever is not common at present, but was so before the new water-supply system was installed. In protecting themselves these communities have protected others, because if typhoid fever is reduced to a minimum the privies and sewers must necessarily turn fewer of the bacilli into the streams. The sources of the water supplies of the most important places in the Potomac basin are given in the following table:

Public water supplies in the Potomac basin.

City.	Supply.	When introduced.
Winchester, Va.	Springs	Colonial period.
	do	1894.
Gettysburg, Pa.	Driven wells	1830.
	Marsh Creek	1893.
Frederick, Md.	Two deep wells	1844.
	Big Tuscarora Creek	1869.
	Little Tuscarora Creek	1891.
	Fishing Creek	1899.
Leesburg, Va.	Rock spring, one-half mile northwest of town	1845.
	New supply	1905.
Staunton, Va.	Buttermilk Spring	1849.
	Springs northwest of city	1876.
Martinsburg, W. Va.	Spring	1873.
	Spring 1 mile west of city	1903.
Romney, W. Va.	Springs	1871.
Chambersburg, Pa.	East Branch Conococheague Creek	1875-76.
Hagerstown, Md.	Diffendal reservoir and Ingram Creek	1881.
	Raven Rock Run	1896.
	Warners Hollow Run	1896.
	Antietam Creek (temporary)	1902.
Waynesboro, Pa.	Mountain brooks	1881.
	do	1886.
Harrisonburg, Va.	Artesian well	
	River water	1897-98.
Elkton, Va.	Springs	1891.
Front Royal, Va.	Spring	1892.
Riverton, Va.	Buys water of Front Royal, Va.	
Hyndman, Pa.	Mountain spring	1892.
Frostburg, Md.	Springs	1892.
	City Water Co., from artesian well and springs	
Piedmont, W. Va.	Savage River	1893.
Westernport, Md.	Buys water from Piedmont, W. Va.	1896.
Keyser, W. Va.	Spring	1893.
Greencastle, Pa.	Eshleman Spring	1894.
	Spangler Spring	1902.
Berkeley Springs, W. Va.	Springs	1894.
Lonaconing, Md.	Charlestown Run	1895.
Waynesboro, Va.	Bakers Spring	1897.
Berryville, Va.	Spring	1899.
McConnellsburg, Pa.	Mountain stream	1900.
Luray, Va.	Spring	1901.
Basic City, Va.	do	1901.
Moorefield, W. Va.	South Fork of South Branch	1903.
Mercersburg, Pa.	Trout Run	1903-4.
Strasburg, Va.		1904.
Charles Town, W. Va.	Spring 1 mile west of town	
Franklin, W. Va.	Spring	
Woodstock, Va.	Springs	

The only places of considerable size, aside from Washington, that use Potomac River or any of its large tributaries for a water supply are Moorefield, W. Va., Cumberland, Md., and Brunswick, Md. Of these Cumberland is the most important. In Brunswick the Potomac water is served to only a few and in Moorefield more people use wells than the water of South Fork.

The minimum flow of the Potomac at Great Falls occurred i
and was 1,063 second feet, and the maximum, 470,000 second-fe
in 1889; but there are long periods every year when the flow i
second-feet or less. Several observers have noted that it is
times of low flow that typhoid fever is rampant in Washington
investigation points to the same conclusion, as is shown by the
obtained from the hydrograph of the river at Point of Rocks.
IX.) It is to be regretted that the gaging station is above Me
River, but it is unlikely that the addition of the waters of that
would materially alter the results obtained and it is consider
gularly fortunate that it was possible to secure both stream
and vital statistics for the same river covering a long period.

Pl. IX shows for the years 1902, 1903, 1904, and 1905 the da
of Potomac River at Point of Rocks, the daily deaths from t
fever in the District of Columbia, and the number of cases of t
fever reported daily at the health office of the District. Th
deaths and the deaths from typhoid fever in the District from A
1874, to December, 1905, inclusive, are shown in the ta
pages 281–282.

Pl. IX shows that typhoid fever is prevalent during periods
water, while there are comparatively few cases in the portions
year when the water is high. At first thought these result
surprising, for it would perhaps be natural to expect that the
of excessive typhoid would occur in flood seasons, when a gre
of filth and excrement are washed into the river. But one
thoroughly familiar with the river realizes that it is the co
recipient of large amounts of fecal matter from the many sewe
multitude of privies that line its banks and that the scourings
mittently washed into the stream are small, indeed, compared
excrement that is every day dropped into it. Therefore it i
fectly natural that when this everyday defilement is concentra
a small stream flow the results should be disastrous, for at such
when typhoid germs are present, the chances of one's drinking
siderable dose of them are many times multiplied. Typhoid fe
known to be a disease of summer and autumn, and therefo
bacilli are most likely to be in the stools at the very time the r
low. If the germs are not present, there will not be typhoid in
of low water. It can be seen from an inspection of the diagra
IX) that low water has occurred in winter, but that there ha
been a large increase of typhoid following. It would be fool
maintain that a rain never brings about an increase of typhoid a
the users of Potomac water. It may do so, provided it washe
large quantity of bacilli and does not at the same time bring
such a dilution of the water containing them that the possibil
drinking them is no greater than it was before. There is an

YPHOID 1

ancing adjustment between dilution and concentration. When-
r dilution is in the ascendant, the chances of drinking typhoid
ms are reduced; whenever concentration prevails, the reverse is
e. It is conceivable that in the case of a city pumping water from
iver there might be an opportunity for a small quantity of excreta
osited on the bank to be carried rapidly past the intake by the
y flood that washed it into the stream, at a time when the pumps
re not in service or were pumping at a low rate. Thus the city
uld escape infection entirely or would feel the effects thereof only
htly. So it is that no rigid law can be laid down concerning the
e at which typhoid fever may prevail at Washington, for it
ends principally on the play of three factors—the presence of
bacilli in the water, the dilution of the water containing them, and
ir concentration in it.

There are two distinct types of water-borne typhoid epidemics.
e is illustrated in the case of New Haven, Conn., which for years
joyed a pure supply, but was suddenly overwhelmed by an epi-
mic caused by the careless disposal of typhoid defecations on the
tershed and their sudden precipitation into the water thereafter.
at is, the city for years enjoyed a considerable degree of immunity,
ddenly experienced an epidemic, and then returned to another
riod of immunity with the passing of accidental conditions. To
s type the disease in Washington does not show a resemblance.
is more like the type described by Whipple and Levy[a] in their
estigation of typhoid fever in the Kennebec Valley in 1902–3.
re the towns which used the Kennebec water experienced a certain
ount of typhoid for some time previous to the epidemic, which
s severe enough to impel the citizens to an investigation of the
ditions that surrounded them. In one respect, however, the
valence of typhoid in Washington differs from that in the Kenne-
Valley. There several large towns, one below another, drew
ir water supply from the river and sewered into it as well. The
ult was that one city passed the contagion on to another and that
excessive prevalence of the disease was extended from the normal
iod of three months (August to October) into nine months (August
April). From the danger of such a position Washington is happily
ieved at present, for Cumberland, Md., is the only other large city
the basin that uses the polluted river as a public water supply. If
nswick, Md., increases its present limited use of Potomac water,
h increase may be fraught with serious consequences to Washing-
. With the growth of the cities in the Potomac basin the time is
nd to come when the springs and mountain brooks that now sup-
them will become inadequate. Then they will have to turn to
river, and then conditions will be like those on the Kennebec.

[a] *Journ. New England Water Works Assoc.*, vol. 19, No. 2.

Typhoid statistics of Washington, D. C., 1874–1905.[a]

Year.	January.		February.		March.		April.		May.		June.		July.	
	Total deaths.	Typhoid deaths	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.
1871														
1875	397	7	385	3	432	6	342	4	303	2	430	6	426	14
1876	297	2	310	5	365	6	296	4	279	3	491	7	567	19
1877	329	1	347	5	367	3	293	4	288	7	388	7	476	12
1878	343	7	286	4	346	4	319	6	374	12	436	12	473	15
1879	374	2	335	2	377	3	334	4	296	7	444	6	490	15
1880	309	6	362	2	333	6	311	2	333	7	447	6	359	10
1881	332	7	348	4	357	3	376	5	284	9	311	4	481	10
1882	333	7	367	10	388	6	338	5	326	8	390	3	444	15
1883	340	6	328	7	432	8	381	9	356	7	368	6	510	18
1884	453	4	402	4	414	6	400	5	349	5	443	10	425	8
1885	379	8	445	4	467	5	430	3	388	1	509	13	395	20
1886	378	10	399	5	438	10	378	8	329	7	388	5	440	17
1887	369	4	310	8	383	7	355	5	331	3	499	5	545	21
1888	408	8	433	8	528	8	407	7	347	5	465	11	515	14
1889	430	16	383	9	470	9	402	6	346	6	484	8	532	28
1890	508	11	394	6	485	19	393	11	455	13	596	24	499	36
1891	414	12	414	7	572	12	697	9	457	6	553	9	580	7
1892	643	14	504	13	491	9	446	7	434	10	584	13	535	22
1893	545	6	461	7	591	6	482	12	473	11	596	12	609	23
1894	471	11	442	5	534	6	474	7	451	6	686	24	535	33
1895	448	3	475	8	515	2	465	2	407	8	425	9	571	12
1896	508	9	493	8	528	4	479	4	394	4	475	7	678	9
1897	492	13	528	4	408	4	415	4	380	6	480	10	520	10
1898	428	8	436	4	480	2	420	9	439	6	508	20	608	26
1899	586	10	515	4	489	7	448	6	425	3	459	7	539	10
1900	489	17	433	6	564	8	576	10	461	6	489	12	730	21
1901	608	7	545	2	554	8	461	2	415	4	457	10	727	16
1902	529	19	449	8	467	12	534	9	453	13	500	9	568	21
1903	575	9	573	5	568	9	459	6	450	6	482	3	530	17
1904	592	5	556	5	621	6	513	6	517	8	500	8	509	16
1905	507	11	551	1	580	5	549	6	423	1	477	3	582	15
Total	13,954	200	13,209	173	14,634	200	13,193	187	11,963	200	14,755	280	16,958	530
Per cent[b]	5.11		3.40		4.11		3.68		3.93		5.08		10.42	

[a] In this table deaths from typhoid-malarial fever have been classed as typhoid deaths.
[b] Percentage of total typhoid deaths for each month in the period to typhoid deaths for entire period.

Year.	August.		September.		October.		November.		December.		Total deaths.	Total typhoid deaths.	Population.	Total death rate per 1,000.	Typhoid death rate per 100,000.
	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.	Total deaths.	Typhoid deaths.					
1874	391	12	277	12	306	12	267	18	263	2	1,504	56			
1875	445	24	356	21	317	25	285	10	293	6	4,411	128	157,000	27.99	79.9
1876	397	24	349	10	331	21	254	10	298	3	4,234	114	162,375	26.07	70.3
1877	414	23	318	20	333	11	284	7	302	5	4,139	105	167,300	24.74	62.8
1878	425	12	303	23	331	21	296	2	321	2	5,253	120	172,377	30.47	69.6
1879	349	18	318	12	251	15	268	9	301	5	4,127	98	177,638	23.23	55.2
1880	313	13	352	13	350	16	280	6	326	8	4,075	95	183,060	22.26	51.3
1881	434	20	403	22	413	40	380	23	311	6	4,430	153	188,653	23.48	81.1
1882	341	20	304	13	356	26	316	7	320	3	4,223	123	191,980	22.00	64.1
1883	399	10	336	19	284	11	357	7	467	10	4,558	118	196,490	23.20	60.0
1884	444	15	426	29	368	32	351	15	366	20	4,841	153	201,110	24.07	76.1
1885	398	19	363	16	325	21	327	9	356	15	4,982	134	205,840	24.20	65.1
1886	423	26	439	18	409	16	360	12	347	17	4,728	151	210,680	22.24	71.7
1887	412	34	433	24	353	21	343	19	361	16	4,694	167	215,630	21.76	77.4
1888	543	24	424	32	428	41	337	20	390	10	5,225	188	222,830	23.45	84.4
1889	506	23	412	35	404	17	367	24	422	32	5,158	213	232,460	22.15	91.6
1890	423	28	443	29	427	35	380	25	451	20	5,534	257	242,520	22.82	105.9
1891	508	25	477	29	495	39	449	26	517	5	6,103	186	253,010	24.12	73.5
1892	529	22	526	37	507	22	424	27	493	20	6,416	216	260,800	24.60	82.8
1893	512	24	470	29	462	25	408	24	520	23	6,119	202	265,600	23.04	76.0
1894	425	33	453	28	482	31	409	27	457	17	5,869	228	270,514	21.69	84.4
1895	556	29	459	61	563	56	449	24	429	21	5,782	235	272,337	21.23	86.3
1896	565	17	410	27	476	25	399	18	427	16	5,832	148	275,562	21.16	53.7
1897	435	18	455	20	400	13	441	10	453	18	5,486	130	277,782	19.75	45.7
1898	469	24	482	23	497	31	480	22	568	16	5,815	191	283,100	20.54	67.1
1899	497	39	509	30	481	28	422	29	493	26	5,863	199	288,500	20.32	68.9
1900	525	41	401	29	452	25	438	28	501	17	6,059	220	294,000	20.59	74.4
1901	471	36	452	28	475	21	429	22	456	16	6,050	172	299,600	20.19	56.4
1902	459	39	421	25	490	32	415	19	497	20	5,788	226	305,400	18.95	74.0
1903	424	26	396	18	450	19	477	8	560	14	5,944	140	311,300	19.09	44.4
1904	507	22	433	25	444	14	454	11	515	9	6,221	135	317,200	19.61	42.5
1905	535	[a] 29	412	23	482	[b] 26	502	14	543	6	6,203	140	323,346	19.18	41.1
Total	14,474	769	13,012	780	13,072	788	12,048	532	13,324	424	165,666	5,141			
Per cent [c]	14.89		15.10		15.26		10.10		8.30						

[a] First filtered water turned into mains August 18, 1905.
[b] All water filtered after October 5, 1905.
[c] Percentage of total typhoid deaths for each month in the period to typhoid deaths for entire period.

In the last thirty-one years there have been 5,085 deaths in Washington from typhoid fever, or an average of 164 a year. If the deaths during this time have been 10 per cent of the cases, as experience in many places shows that they usually are, there have been 50,000 cases of typhoid fever, or an average of 1,600 a year. The table on pages 280 and 281 shows to what degree typhoid fever has been present in Washington since the disease has been reported.

Cases of typhoid fever in the District of Columbia, 1902–1905.

Month.	1902.	1903.	1904.	1905.	Total.
January	.....	84	17	31	132
February	.....	42	23	10	75
March	49	35	41	23	148
April	40	39	25	23	127
May	52	63	32	28	175
June	48	57	41	40	186
July	130	121	101	123	475
August	328	188	226	321	1,063
September	290	138	212	218	858
October	247	148	138	154	687
November	156	88	104	82	430
December	129	54	38	53	274
Total	1,469	1,057	998	1,106	4,630

To protect the District of Columbia against so serious a menace a filtration plant has been built, at a cost of $3,500,000, which it is estimated will cost $100,000 a year to run. Undoubtedly the expenditure is a wise one, but it is an impressive lesson in pollution. Moreover, the end is not yet, for if the pollution is unrestrained the evil results therefrom will make the water more difficult to purify. This means that the present rates of filtration can not be maintained, which will add to the cost of treating the same amount of water and necessitate a larger plant. Common sense demands, therefore, that some check be placed on the extravagance of needlessly fouling the river, for what Washington has been compelled to do will become necessary for other cities in the basin.

QUALITY OF SURFACE WATERS.

FIELD ASSAYS.

Inasmuch as large quantities of coal-mine water are poured into rth Branch at sundry points along its course from Henry to Piedmont, W. Va., it was deemed advisable to investigate its effect on the er, and the study also covered the changes wrought by the large antities of lime sludge and spent lime bleach from the mill of the est Virginia Pulp and Paper Company at Luke, Md.

Mine waters are characterized by large amounts of free sulphuric id, sulphates of lime, magnesia, and alumina, and ferrous sulphate iron. The protosulphate of iron on exposure to the air breaks up, h the formation of ferric hydrate and ferric sulphate. The drate precipitates; the sulphate remains in solution. The protophate of iron has a very destructive corrosive action on steam lers and the sulphates of lime and magnesia form hard incrustans on them which can be removed only at considerable expense and without damaging the plates. The appearance of a stream conninated by mine water is striking and somewhat uncanny, for all getable and animal life is destroyed, and the bright, clear waters ash forbiddingly over the bed, which is stained yellow by the iron.

Field assays were made from September 20 to 23 and from October o 14, 1905. The first trip covered the river from Dam No. 5, above lliamsport, to West Virginia Central Junction, and was not intered with at all by the weather. The second extended from Wilia to Piedmont, W. Va., and was very satisfactory, for there was rainfall until the 11th to increase the stream flow and thereby ange the concentration of the water, which was at low stage.

North Branch above Henry contains but a trace of sulphates and is low alkalinity. The mine water that enters at Henry through a tle nameless run increases the sulphates in the river to such a point at the lumber company at Dobbin has been compelled to abandon e river water for boiler use.

Between Dobbin and Wilson the tributary streams have no sulates, so that by the time Wilson is reached the sulphates have been uted to 35 parts per million, and at Bayard the sulphates have all t disappeared and the water is suitable for boiler use. Buffalo eek, which enters at Bayard, is said to be polluted by mine wastes, t the amount received must be small, because the water is nearly rmal for the region. For some reason which could not be ascerined the sulphates in the river between Bayard and Gormania rise 30 parts per million. Notwithstanding the fact that the run at oyer adds more mine water, North Branch at Stony River contains t a trace of sulphates.

It is interesting to follow the chlorine from Bayard to Schell. The tanneries wash out large quantities of salt from the hides and discharge it in the soaks. Above Bayard the river contained but 6 parts per million of chlorine. At Gormania it rose to 34 parts; inflowing waters diluted this to 19 parts at Stony River and to 14 parts at Schell. Samples taken below this point were collected after a rain, so that the results are not comparable, but this process of dilution undoubtedly would have continued regularly. This is an excellent example of the way factory effluents may be traced in a river by selecting some characteristic, readily detectable salt, and following it downstream.

At Schell the water of North Branch is very soft, owing to the fact that it has received the waters of Stony River, which are remarkably low in dissolved mineral substances. There is no change by the time it reaches a point a little above Harrison, but at this town the waters of Abram Creek, slightly polluted by mine water, fall in. From Harrison downstream, Wolfden Run, Three Fork Run, and Deep Run, in order, join North Branch. All of them are polluted by mine water, and Deep Run, which drains the extensive Elk Garden coal regions, carries a heavier quota of mine waste than any other stream tributary to North Branch, with the exception of Georges Creek. Despite these additions, the river above Elk Lick Run, near Shaw, W. Va., does not contain an objectionable amount of incrusting constituents, though the total hardness is considerably increased. Above Savage River the total hardness becomes low again and the river is in good condition. The entrance of Savage River and of a small volume of mine water below it does not change the water very much, and it soon after flows over the dam of the West Virginia Pulp and Paper Company.

In the entire distance from Henry to West Virginia Central Junction the tributary streams are normally low in objectionable mineral ingredients and by dilution counteract the mine waters which are poured into the river, so that the water arrives at the paper company's dam with practically the same mineral content that it has above Henry. This is somewhat surprising, for prior to the investigations it was believed that the mine water was so considerable as to have a decidedly deleterious effect on the stream.

A short distance below the dam the factory of the West Virginia Pulp and Paper Company discharges its effluent, consisting of carbonate of lime, chloride of lime, and sulphate of soda, into North Branch. The quantity is so great that it converts the clear stream into a turbid, milky-white one, and the tests applied to the water showed the marked effect of the chemicals on it. October 14, 1905, the lime rose from 26 parts per million above the dam to 105 at a point opposite the Baltimore and Ohio roundhouse in Piedmont, the

calinity rose from 31 parts per million to 44, the sulphates from a ace to 56, and the chlorine from 9 to 29. Thus the character of the eam is radically altered by this effluent, and it is still further anged by the influx of the waters of Georges Creek, which enter at esternport and which are heavily charged with mine waters. The aters of the creek when they unite with those of North Branch act with the matter which it contains in suspension and solution. ee sulphuric acid combines with the carbonate of lime, producing a ecipitate which makes the water roily and may be observed all e way from Westernport to Keyser. The iron salts, including the ric sulphate, are precipitated in the form of ferric oxide.

September 23 there were in the waters of North Branch above the m at West Virginia Central Junction 26 parts per million of lime, of alkalinity, a trace of sulphates, and 9 parts of chlorine. At e Baltimore and Ohio roundhouse there were 130 parts of lime, 47 alkalinity, 117 of sulphates, 24 of chlorine, and 1 of iron. Georges eek contained 288 parts of calcium, 522 of sulphates, and 54 of n. One mile below Westernport, North Branch contained 130 rts of calcium, 6 parts of alkalinity, 185 parts of sulphates, and 3 parts of iron. It is evident from these results that the sulphuric id combined with the carbonates represented in the test by alkaity to the extent of nearly eliminating them. The sulphate of lime med thereby was considerable, and the iron for the most part preipitated out or became obscured by dilution. By following the tests the table on pages 287–290, it becomes apparent that from a point nile below Westernport the alkalinity steadily increased in amount Dam No. 5, being 38 parts per million 2 miles below Keyser, 46 the Cumberland waterworks intake, and 73 at Dam No. 5, at illiamsport. That is, after partial elimination the carbonates nded to return to the normal for the region. Moreover, the sulates dropped steadily, being 181 parts per million 2 miles below eyser, 140 at Cumberland, and but a trace at Dam No. 5.

This extensive precipitation has a potent influence on the bacrial content of North Branch, for the sulphates in settling out tangle the germs and drag them to the bottom, thus decidedly proving the water. In Georges Creek the acid waters are unubtedly inimical to the bacteria and tend to destroy the organic tter which is so abundantly supplied to the stream at the numers thriving mining towns in its valley. This reduces the effect of e pollution of North Branch at Westernport. Finally, as has en shown by experiments described elsewhere,[a] the waste disarged by a soda pulp mill is a powerful germicide and an excellent ecipitant of sewage.

[a] Leighton, M. O., Preliminary report on the pollution of Lake Champlain; Water-Sup. and Irr. er No. 121, U. S. Geol. Survey, 1905.

Together, these several influences effect so considerable a reduction of the bacteria in North Branch that its water is used raw by the city of Cumberland with results much less evil than the gross pollution of the watershed would lead one to expect. While this is fortunate, it is to be remembered that the purification is effected by a number of factors acting independently of each other, without intent of improving the water. A diminution of the output of the paper mill or of the flow from the pumps at the mines would at once interfere with the purification and might lead to serious results. Fortunately, the stream flow is usually low at that season of the year when typhoid fever is most prevalent, so that the proportion of chemicals in the water is greatest when it is most needed. It is manifest that this quasi purification must be uncertain and that it is dangerous to depend on it. Therefore it is obvious that the city of Cumberland should install proper water-purification works without delay. As it is a manufacturing city, and as the sulphates in the North Branch water at this point are sufficient to cause some trouble by the formation of hard scale in boilers, it might be profitable to establish also a water-softening plant. The amount of iron in the surface and subsoil waters of North Branch above Cumberland is usually great enough to compel the use of casings to exclude it from wells which are driven for industrial enterprises.

The field tests made on the waters of Wills Creek indicate that above Jennings Run the water is low in incrustants. The run is heavily polluted by mine water, and consequently raises the sulphates in Wills Creek sufficiently to make the water harmful for steam-producing purposes. The assays of various springs and wells in the Wills Creek valley show them to differ considerably, the water in some being soft and in others very hard.

The tests applied to Conococheague Creek show that a small amount of sulphates is usually present and that the water has a varying amount of temporary hardness, which is more marked in the waters of West Branch than in those of the main stream.

The headwaters of the Monocacy about Gettysburg, Pa., to wit, Rock Creek, Marsh Creek, Stevens Run, and Willoughby Run, show different characteristics by the field tests. Marsh Creek water is the softest and gives more satisfaction in Gettysburg for boiler use than those from the deep wells, all of which are corrosive and high in incrustants. Some of these wells will very likely soon be abandoned on account of these bad qualities.

Field assays of waters in Potomac River basin.

[Parts per million.]

tream.	Date.	Acidity.[a]	Calcium.	Alkalinity.	Total hardness.	Sulphates.	Chlorine.	Iron.
Wilsonia, W. Va....	Oct. 4,1905	8	Trace.	259	.....	0	9	1
ı Potomac River and above creek[b]...	.....do.....	8	Trace.	24	22	Trace.	6	2
·. W. Va.[c].....	.....do.....	20	119	38	90	155	9	4
nouth.....	.....do.....	5	0	15	12	0	6	0
ı Potomac River t Dobbin, W. Va....	.....do.....	8	67	22	51	77	6	2
ıat supplies Dobbin	.....do.....	15	Trace.	8	12	0	4	1
ɔin, W. Va., east of West Virginia Cen- sburg R. R. track...	.....do.....	45	Trace.	8	22	0	6	0
ɔrthwest of Dobbin.	.....do.....	10	Trace.	16	12	0	4	2.2
ıt Wilson, W. Va.[d]	.....do.....	5	Trace.	16	18	0	6	0
Potomac River at ·a., below Red Oak	.....do.....	8	32	17	.....	29	6	2.2
., opposite Wilson,	.....do.....	10	Trace.	17	18	0	6	2
Potomac River at Va., above Buffalo	.....do.....	5	24	18	.....	Trace.	6	1.5
ıt Bayard, W. Va...	.....do.....	5	Trace.	8	18	Trace.	6	0
Potomac River at w Buffalo Creek and	.....do.....	5	28	19	27	Trace.	6	1.5
& Sons Co.'s drilled ania, W. Va.[d]	Oct. 9,1905	12	47	143	51	0	8	.5
ı Potomac River ay bridge at Gor-	Oct. 10,1905	15	55	35	49	33	34	2
Potomac River	Oct. 6,1899	.....	41.04	.....	128.2	22	28.7	2.86
at Gorman, Md....	Oct. 9,1905	8	26	36	27	Trace.	4	1
nouth.....	Oct. 10,1905	5	26	34	22	Trace.	4	.5
Md.....	Oct. 8,1905	5	39	22	32	Trace.	6	.5
t mouth.....	.....do.....	5	Trace.	24	32	0	9	0
ı Potomac River e above Stony River.	.....do.....	5	26	24	27	Trace.	19	1
·. Va., at mouth....	.....do.....	5	0	9	12	0	9	1
ı Potomac River l Run and opposite	.....do.....	5	Trace.	21	12	Trace.	14	1
mouth.....	.....do.....	5	Trace.	18	18	0	4	0
near mouth.....	.....do.....	5	0	14	10	Trace.	9	0
ı Potomac River ı Creek.....	Oct. 12,1905	10	Trace.	13	18	Trace.	9	1.5
t mouth.....	.....do.....	10	Trace.	13	32	Trace.	9	1.5
Md.[f].....	.....do.....	60	48	Acid.	66	60	9	7
n, Md., northeast of Va.....	.....do.....	10	Trace.	24	22	Trace.	4	0
ıaw, W. Va.[f].....	.....do.....	140	119	Acid.	.....	273	19	8
Shaw, W. Va.....	.....do.....	5	Trace.	28	22	Trace.	4	1
ı Potomac River ck Run, Md.....	.....do.....	15	Trace.	17	61	Trace.	14	2.2
northeast of Shaw.	.....do.....	5	23	40	.....	Trace.	9	.....
ı Potomac River · River.....	Oct. 14,1905	10	24	20	27	Trace.	9	1.7
ear mouth[g].....	Apr. 5,1905	.....	0	25	.....	0	9	Trace.
ap in Kenny House. ·. Va.....	Oct. 3,1905	5	27	44	.....	Trace.	9	0
ear mouth.....	Oct. 14,1905	5	Trace.	26	18	Trace.	9	0
ı Potomac River Virginia end of dam	Sept. 23,1905	.....	26	18	32	Trace.	9	1
.....	Oct. 14,1905	5	26	31	27	Trace.	9	1

illion of $CaCO_3$ required to neutralize the acidity.
ed by mine water.
ich mine water.
t to keep out iron-bearing water, which is said to be found 10 to 20 feet below surface of
North Branch of Potomac valley above Cumberland, Md.
Prof. J. W. Mallet.
mine water.
J. Lewis.

Field assays of waters in Potomac River basin—Continued.

Stream.	Date.	Acidity.	Calcium.	Alkalinity.	Total hardness.	Sulphates.	Chlorine.	Iron.
North Branch Potomac River above pulp mill at Luke, Md.[a]	July 14, 1899	.....	6.93	.....	24.7	17	4.6	1
North Branch Potomac River opposite Baltimore and Ohio roundhouse, Piedmont, W. Va.	Sept. 23, 1905	.....	130	47	.....	117	24	
Do.	Oct. 14, 1905	5	105	44	90	56	29	
North Branch Potomac River at Piedmont, W. Va.[b]	Apr. 4, 1905	.....	73	40	.....	10	.....	
Georges Creek at mouth	....do	.....	.....	Acid.	.....	410	.....	
Do.	Sept. 23, 1905	.....	288	.....	.....	522	.....	
Do.	Oct. 14, 1905	462	228	.....	.....	359	19	
Do.[a]	July 14, 1899	.....	129.54	.....	439.1	502	10	1
North Branch Potomac River, West Virginia side, 1 mile below Westernport, Md.	Sept. 23, 1905	.....	130	6	.....	185	19	
North Branch Potomac River, Maryland side, 1 mile below Westernport, Md.	Oct. 14, 1905	10	130	26	100	115	14	
North Branch Potomac River, West Virginia side, 2½ miles below Westernport, Md	Sept. 23, 1905	.....	126	8.5	.....	185	19	
North Branch Potomac River, West Virginia side, 1 mile above Keyser, W. Va.	....do	.....	133	19	.....	164	19	
North Branch Potomac River at Keyser, W. Va.[a]	Apr. 27, 1905	.....	73	10	104	64	9	
Do.	Sept. 23, 1905	.....	130	17	.....	159	19	
New Creek[a] ¼ mile above mouth	July 14, 1899	.....	45.08	.....	113.7	20	32.4	
New Creek at mouth	Sept. 23, 1905	.....	123	128	.....	Trace.	39	
Keyser city supply (impounded spring water)	Apr. 27, 1905	.....	261	171	.....	15	9	
Do	Sept. 23, 1905	.....	179	211	.....	Trace.	4	
North Branch Potomac River below Keyser, W. Va.[a]	—— , 1899	.....	48	.....	156	202	11.9	
Do[a]	—— , 1899	.....	78.6	.....	200	406	22.6	
Do[a]	—— , 1899	.....	63.1	.....	156	290	20.3	
North Branch Potomac River at Baltimore and Ohio R. R. bridge 21, Maryland side, 2 miles below Keyser	Sept. 23, 1905	.....	130	38	.....	151	19	
North Branch[b] Potomac River above Cumberland, Md.	— , 1899	.....	56	.....	171	206	12.1	
North Branch Potomac River (hydrant in Cumberland, Md.)[a]	, 1899	.....	31.12	.....	128.5	110	13.6	
North Branch Potomac River, at Ridgely above Cumberland waterworks intake[b]	Apr. 4, 1905	.....	55	20	118	78	9	
North Branch, Potomac River, at Cumberland waterworks intake	Sept. 22, 1905	.....	123	46	.....	117	14	
North Branch Potomac River, 300 feet below dam at Cumberland, Md.[b]	Apr. 3, 1905	.....	96	25	.....	84	9	
North Branch Potomac River above sewage outfall at South Cumberland[b]	Apr. 4, 1905	.....	.....	.....	.....	68	.....	
Chesapeake and Ohio Canal at lock above Dam No. 5, where canal enters river	Sept. 20, 1905	.....	69	62	61	33	15	
North Branch Potomac River below Dam No. 5	....do	.....	70	73	.....	Trace.	9	
Kilmer Spring, public water supply, Martinsburg, W. Va.[b]	Aug. 14, 1905	.....	126	205	.....	0	27	
Public water supply, Hyndman, Pa.	Apr. 7, 1905	.....	0	7	.....	0	7	
Wills Creek west of Hyndman, Pa.[b]	Apr. 8, 1905	.....	0	10	35	Trace.	9	
Wills Creek, 100 yards below tannery[b]	Apr. 9, 1905	.....	0	15	.....	Trace.	9	
Wills Creek at Corriganville[b]	Apr. 4, 1905	.....	Trace.	25	.....	10	9	
Jennings Run at mouth[b]	....do	.....	63	Acid.	.....	239	79	
Braddock Run at narrows[b]	....do	.....	30	35	.....	10	9	
Wills Creek at Cumberland[b]	Apr. 3, 1905	.....	110	.....	.....	90	.....	
Wills Creek, west side, 2,000 feet above mouth[a]	July 15, 1899	.....	48.6	.....	168.6	245	41.7	

[a] Analysis by Prof. J. W. Mallet. [b] Assay by S. J. Lewis.

Field assays of waters in Potomac River basin—Continued.

am.	Date.	Acidity.	Calcium.	Alkalinity.	Total hardness.	Sulphates.	Chlorine.	Iron.
feet deep, 1 mile ey, Pa.[a]	Apr. 8, 1905	.....	55	44	.....	18	19	Trace.
lle east of Foley,	do	.....	0	12	28	0	9	0
Fairhope, Pa., ½ s Creek[a]	do	.....	0	13	21	0	9	Trace.
s, Pa., south side ove Wills Creek[a]	do	.....	0	17	35	0	9	0
g at Hoblitzell,	do	.....	82	62	97	Trace.	9	0
ık Wills Creek op- ory[a]	do	.....	Trace.	14	28	Trace.	9	Trace.
Wills Mountain, 's house, 2 miles n, Pa.[a]	Apr. 7, 1905	.....	0	20	.....	0	9	0
s well, 1½ miles n, Pa., at String-	do	.....	228	152	.....	24	80	0.5
Cooks Mills, Pa.[a]	do	.....	20	29	63	6	9	0
Cooks Mills, Pa.	do	.....	146	44	.....	30	22	.....
t of Cooks Mills,	do	.....	173	187	.....	6	9	.....
t Spangler Hotel,	Apr. 18, 1906	.....	142	115	.....	108	129	0
Creek at Na- tween Hancock ld	do	.....	Trace.	14	21	Trace.	4.5	0
ational Road be- , Md., and Big	do	.....	34	45	35	Trace.	45	0
reek above Wolf nbersburg, Pa	Sept. 15, 1905	.....	46	58	42	0	4	0.0
n above mouth	do	.....	186	[b] 178	.....	Trace.	4	Trace.
reek below Ger- ory, Chambers-	do	.....	96	96	80	Trace.	4	0.0
ek, tap in Wash- y supply	Sept. 16, 1905	.....	35	56	.....	0	9	Trace.
ek, 1 mile west of	Sept. 18, 1905	.....	110	118	80	Trace.	9	0.0
ublic supply, tap el, supply from 3	do	.....	0	202	.....	Trace.	9	0.0
rcersburg Water 1 mile north of east of Mercers- Dickys Run	Sept. 17, 1905	.....	Trace.	26	.....	0	9	0.5
Conococheague	Sept. 16, 1905	.....	113	[b] 127	90	Trace.	9	0.5
mouth	do	.....	71	208	.....	Trace.	14	0.5
Conococheague outheast of Mer- low Dickys Run	do	.....	90	[b] 98	71	Trace.	9	Trace.
r mouth	do	.....	94	132	80	Trace.	9	Trace.
eek near mouth	Sept. 20, 1905	.....	96	[b] 108	80	Trace.	14	Trace.
ettysburg, Pa.	Sept. 9, 1905	.....	200	204	.....	36	89	0.0
Culps Run, Get-	do	.....	84	91	.....	Trace.	14	2.5
Gettysburg Wa-	do	.....	32	[b] 41	.....	Trace.	9	Trace.
Gettysburg, Pa.	do	.....	100	106	71	Trace.	4	0.0
mile west of Mc- , public supply	Sept. 17, 1905	.....	Trace.	27	.....	Trace.	4	0.0
t end of McCon-	do	.....	137	158	.....	Trace.	4	0.0
Creek west of	Sept. 12, 1905	.....	137	[b] 194	.....	Trace.	9	0.0
, public supply aynesboro water e of Rattlesnake ranch Antietam	do	.....	0	[b] 21	.....	0	4	Trace.

[a] S. J. Lewis.

[b] Alkaline carbonates, 21 parts per million.

Field assays of waters in Potomac River basin—Continued.

Stream.	Date.	Acidity.	Calcium.	Alkalinity.	Total hardness.	Sulphates.	Chlorine.	Iron.
East Branch Little Antietam Creek east of Waynesboro, Pa.	Sept. 12, 1905	.....	28	a 51	.....	0	4	Trace.
Spanglers Spring at Gettysburg, Pa.	Sept. 9, 1905	.....	39	85	42	0	9	0.0
Well of Gettysburg Brick Co. at Gettysburg, Pa.	do.	.....	218	250	.....	0	14	0.0
Well of Gettysburg Transit Co. at Gettysburg, Pa.	do.	.....	200	173	.....	Trace.	29	0.0
Well of Western Maryland R. R. at Gettysburg, Pa b	do.	.....	123	291	.....	110	258	0.5
Steam laundry dug well at Gettysburg, Pa.	Sept. 10, 1905	.....	72	79	.....	Trace.	29	0.0
Gettysburg Water Co.'s Well No. 1, Gettysburg, Pa.	Sept. 9, 1905	.....	23	41	51	Trace.	9	0.0

a Alkaline carbonates, 21 parts per million.

b Magnesium present.

SANITARY AND MINERAL ANALYSES.

By Raymond Outwater.

Numerous chemical analyses of the waters of the Potomac have been made during the course of this investigation, and the results are given in the accompanying table. It is very difficult to draw definite conclusions of a general nature from these sanitary analyses. Inspection of the various places on the river and its tributaries points to a considerable pollution at practically all of the places examined and the chemical analyses confirm the inspections. Evidences of pollution can, in some instances, be seen in the main stream after pollution has entered it; yet chemical analysis does not indicate that the water is much more polluted at Great Falls than at many points farther up the river and on its tributaries.

The tap water was collected in the McKinley School of Manual Training. The water supplied to this building flows from the river to the Dalecarlia Reservoir, thence to the distributing reservoir in Georgetown, and thence to the Washington City Reservoir, from which it flows by gravity through the street mains to the laboratory. None of the water supplied to Washington during the progress of the chemical examination was filtered.

A study of the analyses leads to the following conclusions:

1. The variations in the amount of each component have been considerable, and these are to a certain extent unaccounted for.

2. A certain proportion of the variations can possibly be accounted for by the variation in the rainfall.

3. If these analyses are of accuracy equal to those obtained by previous investigations they indicate that the river has become more impure, the figure for required oxygen being the only one which shows a decrease.

e mineral analyses which were made represent the main stream
ll of the principal tributaries, and it is believed that they give
sight into the chemical denudation of the basin. The purpose
ese analyses was to determine the amount and the nature of the
lved mineral matter. The water was filtered through a Pasteur-
mberland filter; measured quantities were then evaporated
ly to dryness in porcelain vessels, after which the evaporation
completed in platinum dishes. The residue thus obtained was
ted with hydrochloric acid and twice evaporated to dryness,
which it was redissolved in hydrochloric acid and the silica
separated by filtration, ignited, and weighed. The residue left
r treatment with hydrofluoric acid was added to the "iron and
mina." The filtrate from the silica was diluted to 200 c. c. and one
ion of 100 c. c. was taken for the estimation of iron and alumina,
ium, and magnesium, and the other portion for the estimation
ulphuric acid, sodium, and potassium. This method of determin-
sodium and potassium is preferable to the common one of sepa-
ng sodium and potassium in the filtrate from the magnesium.
s unnecessary to detail the methods, which may be found in
dard text-books on quantitative chemical analysis.

me interesting facts are brought out by comparing the flow of
Potomac with the analytical results. For this purpose, the gage
lings at Point of Rocks, Md., 7 miles above the Monocacy River,
e used, no gage being maintained by the United States Geolog-
Survey below this point. As most of the analyses were of sam-
from the Washington city taps, which are fed with water diverted
n the river at Great Falls, the results are not strictly accurate,
they are approximately so.

he average flow of the Potomac at Point of Rocks for 1905 was
ulated from observations made by the United States Geological
vey and was found to be 7,534 second-feet. As the weight of a
ic foot of water is 28.3 kilograms (62.4 pounds), this is equal to
212 kilograms per second. Calculating the total amount of
er flowing past this point from the average, we have for the year
4,000,000,000 kilograms or liters. From the figures on analyses
nave: Total solids in the unfiltered water, 146.1 parts per million;
l solids in solution, 114.6 parts; in suspension, 31.5 parts; from
ch we find that the following amount of material is carried past
point in the course of a year: Total solids, 982,000,000 kilograms;
olution, 771,000,000 kilograms; in suspension, 212,000,000 kilo-
ns; or, in solution, 850,000 tons; in suspension, 234,000 tons.

he drainage area of the Potomac above Great Falls is 11,400
are miles. By comparing this area with the amount of material
g carried down in suspension and in solution, the following figures,
wing the average amount of solid material being carried off annually

from each square mile of territory in the Potomac basin, are obtained: In solution, 74.4 tons; in suspension, 20.5 tons; total, 94.9 tons.

Sanitary analyses of surface water in the Potomac basin.

[Parts per million.]

Stream.	Date.	Required oxygen.	Nitrogen as—				Chlorine.	Unfiltered water.		
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total residue.	Loss on ignition.	Total hardness.
North Branch Potomac River above Bayard	Feb. 27, 1905	1.65	0.16	0.12	Trace.	3.00	6	26	19	29.4
Buffalo Creek at mouth	do	1.70	.06	.05	Trace.	1.50	9	39	15	39.7
North Branch Potomac River above Gormania	Feb. 25, 1905	2.15	.11	.07	.002	1.25	4	30	15	42.6
North Branch Potomac River below Gormania [a]	Oct. 6, 1899	26.42	.676	.182	.023	.261	28.7	311.6	140.7	126.2
Do	Feb. 25, 1905	1.95	.13	.06	Trace.	2.00	9	46	17	55.9
Abram Creek at mouth	Feb. 27, 1905	.85	.15	.19	Trace.	2.50	5	47	26	51.5
North Branch Potomac River above Savage River	Feb. 25, 1905	1.80	.15	.02	0	3.00	11	23	9	30
Savage River	do	.80	.06	Trace.	0	3.00	5	32	15	33.8
North Branch Potomac River above mill of West Virginia Pulp and Paper Co. at Luke	July 14, 1899	7.76	.234	.154	Trace.	.171	4.6	59.4	25.5	24.7
Do	Feb. 25, 1905	1.45	.18	.09	0	2.50	15	57	18	30
North Branch Potomac River below mill of West Virginia Pulp and Paper Co. at Luke	do	3.20	.09	.05	Trace.	3.00	25	448	177	120.5
Georges Creek at Westernport	July 14, 1899	13.05	.446	.591	.011	1.422	10.1	1013	222.6	439.1
Do	Feb. 25, 1905	2.35	.06	.51	Trace.	2.50	17	1057	442	524.8
North Branch Potomac River between Keyser and Piedmont	do	1.80	.06	.06	0	2.5	10	145	50	63.2
North Branch Potomac River below mill at Keyser	do	2.35	.09	.05	Trace.	2.50	11.0	189	60	97.0
New Creek ¼ mile above mouth [a]	July 14, 1899	11.26	.371	.137	.069	.933	32.4	218.8	69.4	113.7
New Creek at mouth	Feb. 25, 1905	2.80	.46	.30	.004	2.50	22	233	81	105.8
North Branch Potomac River below Keyser [a]	1899	.....	.380	.054	.16	2.31	11.9	452	194.5	100.6
Do	1899	.....	.483	.081	.11	.74	22.6	853	368	140.3
North Branch Potomac River above Cumberland	1899	.....	.295	.075	.....	2.86	12	491.8	220.8	110.5
Do	1899	.....	.397	.142	.....	1.09	20.3	658	315.4	100.9
Hydrant in Cumberland	July 15, 1899	23.689	.374	.163	.005	.219	13.6	276.5	104.9	128.5
Cumberland water supply	Dec. 29, 1904	7.45	.32	.37	Trace.	1.20	5.0	126	47	73.3
Wills Creek above Jennings Run	Dec. 27, 1904	4.60	.17	.03	Trace.	.80	15	82	38	50.8
Jennings Run at mouth	Dec. 29, 1904	1.75	.08	.44	Trace.	.80	20	632	243	290
Braddock Run at Allegany Grove	Dec. 27, 1904	1.70	.28	.06	Trace.	1.00	14	115	33	78
Wills Creek above dam of United States Leather Co., Cumberland	Dec. 30, 1904	8.95	.74	.52	.002	.80	7	147	38	92
Wills Creek above Baltimore Street Bridge, Cumberland	do	13.95	.66	.40	.004	.90	17	224	60	137.3
Wills Creek 100 yards above dam at mouth [a]	July 15, 1899	32.476	.909	.827	.008	.257	41.7	372.5	135.2	168.6
Patterson Creek at mouth	Feb. 13, 1905	.45	.05	Trace.	0	1.00	8.0	142	55	129.5
North Branch Potomac River at Greenspring	Feb. 10, 1905	2.10	.35	.27	.008	2.00	14.5	219	63	152.9
South Branch Potomac River at Franklin above tannery	Mar. 11, 1905	1.70	.29	Trace.	0	1.12	3.50	85	35	80.9
North Fork of South Branch Potomac River above South Branch	Mar. 12, 1905	1.75	.17	.01	0	1.00	2.5	83	25	42.6

[a] Analysis by Prof. J. W. Mallet.

itary analyses of surface water in the Potomac basin—Continued.

ı.	Date.	Required oxygen.	Nitrogen as—				Chlorine.	Unfiltered water.		
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total residue.	Loss on ignition.	Total hardness.
Potomac Peters-										
dy Coun-	Mar. 10, 1905	1.85	0.31	0.03	0	1.25	4.0	171	26	55.9
Potomac Peters-	.....do.....	2.10	.17	.03	0	1.30	3.5	199	48	66.2
Potomac Moore-	.....do.....	1.95	.22	.07	0	1.25	3.0	220	41	50.0
er above	.....do.....	2.00	.13	.03	0	1.25	2.5	276	32	47.0
oorefield .	Mar. 9, 1905	1.90	.12	.02	0	1.50	4.5	258	29	47.0
er below										
oorefield .	.....do.....	2.40	.21	.01	0	1.25	4.0	471	44	44.1
Potomac Moore-										
	Mar. 10, 1905	2.10	.13	.03	0	1.50	3.5	498	77	60.3
omney...	Mar. 13, 1905	1.65	.12	.03	0	1.25	4.5	119	32	50.0
Potomac Romney..	.....do.....	1.30	.14	.03	Trace.	1.25	3.0	98	28	55.4
Romney.	.....do.....	1.70	.36	.03	Trace.	1.40	7.5	93	29	35.3
Potomac ıth.....	Feb. 10, 1905	1.15	.11	Trace.	Trace.	2.00	7	120	43	123.2
r below										
h.....	.....do.....	1.15	.13	Trace.	Trace.	2.00	8.1	127	48	121.7
r above										
	.....do.....	1.30	.22	.09	.004	2.00	8	156	49	127.9
r below										
	.....do.....	2.20	.24	.10	.004	2.00	14	176	57	157.6
r above										
n River..	Feb. 12, 1905	.90	.10	.01	Trace.	.88	8	162	54	135.7
River at										
	.....do.....	1.35	.11	.08	0	1.00	5	108	37	82.7
r below										
n River..	.....do.....	.70	.03	Trace.	0	.75	4	94	35	93.6
Run.....	Feb. 10, 1905	.50	.03	.08	.012	2.25	6	181	53	165.4
Creek										
ersburg..	Mar. 31, 1905	.40	.04	.03	0	1.00	3.5	135	93	47.0
Creek										
ersburg..	.....do.....	.50	.08	.03	Trace.	4.00	8	233	147	91.0
f Conoco-										
k above										
	Apr. 1, 1905	.65	.14	.02	Trace.	3.00	4.5	159	31	130.8
f Conoco-										
k below										
	.....do.....	.70	.08	.01	Trace.	3.50	5.0	127	43	105.8
ove Wil-										
	Mar. 31, 1905	.25	.22	.02	Trace.	2.00	4.5	101	40	126.4
low Wil-										
	.....do.....	2.10	.16	.04	Trace.	3.50	5.5	77	66	129.4
Creek be-										
ek.....	.....do.....	.60	.13	.05	Trace.	5.00	5.5	222	66	192.6
Creek be-										
n with										
ı.....	Apr. 1, 1905	.55	.12	.02	Trace.	2.50	5.0	115	80	137.6
er above										
ue Creek..	.....	.50	.12	.02	Trace.	2.25	4.0	104	16	47
er below										
ue Creek..	.....	.50	.17	.03	Trace.	2.75	7.0	165	33	125
k above										
k.....	Feb. 18, 1905	.40	.10	.01	.008	2.50	9	271	121	276.1
	.....do.....	2.25	.19	.03	.016	5.00	17	334	140	224.9
k below										
k.....	.....do.....	2.05	.17	.04	.012	2.75	15	305	25	157.3
k above										
reek.....	Feb. 17, 1905	.45	.04	.03	.004	5.00	19	303	62	280.8
k.....	.....do.....	1.50	.46	.07	.128	5.00	17	328	129	305.8
ek near										
	.....do.....	.70	.11	.03	.024	5.50	12	284	56	266.4
er above										
ek.....	.....do.....	.40	.12	.10	.004	2.50	13	178	87	123.5
er below										
ek.....	.....do.....	.90	.10	.03	.024	2.75	20	164	22	210.2
er above										
eek.....	Jan. 17, 1905	3.33	.25	.08	Trace.	1.00	8.5	185	22	93.2

Sanitary analyses of surface water in the Potomac basin—Continued.

Stream.	Date.	Required oxygen.	Nitrogen as—				Chlorine.	Unfiltered water.		
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total residue.	Loss on ignition.	Total hardness.
Antietam Creek at mouth	Jan. 17, 1905	1.95	0.15	Trace.	0.004	2.50	10	216	46	148.8
Potomac River below Antietam Creek	....do....	2.65	.41	0.03	.004	2.50	2.5	238	67	150.1
North River above Cooks Creek	Jan. 28, 1905	1.35	.16	Trace.	Trace.	1.00	11	137	39	137.3
Blacks Creek	....do....	4.35	.69	.86	.032	2.50	33	344	81	248
North River below Cooks Creek	....do....	1.05	.16	.02	Trace.	1.25	15	147	39	170
Middle River above Lewis Creek	....do....	1.15	.07	.12	0	1.25	4	219	42	218.4
Lewis Creek near mouth	....do....	2.25	.47	1.52	.064	3.00	16	365	67	230.9
South River above Basic	Jan. 25, 1905	1.25	.17	.01	Trace.	1.50	6	110	36	117
South River below Basic	....do....	1.90	.13	.03	.002	1.00	4	112	35	109.2
South Fork of Shenandoah River above Elk Run	Feb. 4, 1905	1.15	.14	.02	.003	3.50	6	152	52	105.7
Elk Run	....do....	21.45	1.12	.06	Trace.	4.00	67.0	214	145	53.4
South Fork of Shenandoah River below Elk Run	....do....	3.85	.14	.02	.002	4.00	12	157	66	145
South Fork of Shenandoah River above Hawksbill Creek	Jan. 26, 1905	1.15	.14	.01	Trace.	1.75	7	143	42	137.3
Hawksbill Creek above Luray	....do....	1.00	.09	.01	0	2.00	9	124	45	69.7
Do	Feb. 3, 1905	1.05	.8	Trace.	.001	4.00	15	138	44	77
Hawksbill Creek below Luray	....do....	4.35	.48	.03	.002	3.50	24	175	85	94.5
South Fork of Shenandoah River below Hawksbill Creek	Jan. 26, 1905	2.35	.21	.05	Trace.	1.50	10	143	47	120.1
South Fork of Shenandoah River at Riverton	....do....	1.15	.08	.30	Trace.	1.25	13	109	29	121.5
North Fork of Shenandoah River above Passage Creek	Feb. 2, 1905	1.70	.14	.09	Trace.	2.00	9	200	82	180.1
Passage Creek	....do....	1.50	.10	.01	0	1.00	5	78	37	88.1
North Fork of Shenandoah River below Passage Creek	....do....	1.95	.16	.24	Trace.	1.25	6	189	81	160.6
Happy Creek	Feb. 3, 1905	1.00	.24	.03	Trace.	1.7	8	71	12	75.6
Shenandoah River below confluence of North and South forks	Feb. 2, 1905	1.25	.15	.16	Trace.	1.75	6	173	65	141.8
Evitt Run	Jan. 16, 1905	.95	.06	.01	.004	2.50	11.5	278	93	312
Flowing Spring Run	Jan. 18, 1905	3.00	.72	.21	.024	5.00	9.5	373	123	277.7
Shenandoah River at mouth	July 4, 1904	1.55	.32	.02	.004	.50	4.0	243	55	117.3
Do	Dec. 12, 1904	1.85	.10	.25	Trace.	2.00	4.0	182	34	124.2
Do	Dec. 20, 1904	1.20	Trace.	Trace.	.001	.50	4.0	241	51	172.5
Potomac River above Shenandoah River	July 4, 1904	1.45	.33	.01	.004	.50	5.0	195	59	89.7
Do	Dec. 12, 1904	3.35	.24	.01	Trace	2.00	7.0	215	.....	138
Do	Dec. 20, 1904	2.15	.12	Trace.	.004	.50	8.0	229	55	156.7
Potomac River below Shenandoah River	Dec. 12, 1904	2.75	.22	.01	Trace.	2.00	7.0	217	20	148.9
Do	Dec. 20, 1904	1.35	.70	.25	.004	.50	8.0	222	57	151.8
Catoctin Creek, Md	Jan. 19, 1905	1.40	.14	Trace.	Trace.	2.50	7.0	260	13	42.6
Catoctin Creek, Va	Jan. 18, 1905	.95	.01	.05	Trace.	1.50	6.0	71	26	40.2
Monocacy River above Carroll Creek	Jan. 12, 1905	1.88	.26	.22	.008	1.50	6.0	111	21	.....
Carroll Creek above Frederick	Jan. 13, 1905	2.05	.14	.20	.008	1.50	9.0	182	40	129
Carroll Creek near mouth	....do....	2.65	.38	.48	Trace.	2.50	10.0	220	76	127
Monocacy River below Carroll Creek	Jan. 12, 1905	2.00	.18	.13	Trace.	1.35	8.0	100	28	62
Monocacy River at mouth	Jan. 16, 1905	1.40	.13	.02	Trace.	1.50	3.0	115	42	82.8
Potomac River above Monocacy River	Jan. 12, 1905	2.20	.17	.10	Trace.	1.45	6.0	219	47	138
Do	Jan. 16, 1905	1.50	.12	.02	Trace.	2.00	6.0	222	64	138
Potomac River below Monocacy River	Jan. 12, 1905	1.50	.34	.01	Trace.	2.00	4.5	111	39	89
Do	Jan. 16, 1905	1.40	.14	.10	Trace.	2.00	5.5	121	41	89
Goose Creek	Jan. 30, 1905	1.50	.16	.92	.002	1.75	5.0	61	14	43.7
Seneca Creek	Mar. 27, 1905	.20	.18	.05	Trace.	.....	6.5	74	13	30.8
Calvin Run	Mar. 10, 1905	2.40	.18	.09	0	2.25	5.0	73	24	211.7

Sanitary analyses of tap water at Washington.

[Parts per million.]

ate.	Required oxygen.	Nitrogen as—				Chlorine.	Unfiltered water.		Total hardness.	Suspended matter.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total solids.	Loss on ignition.		
M.										
.....	.....	0.37	0.02	.....	0.2	3.0	127	.....	.....	40
.....	.....	.....	.....	.....	.....	.....	109	26	.....	30
.....	.....	.19	.08	0	.25	3.0	91	.....	.....	11
.....	.....	.....	.....	.....	.....	2.5	121	.....	.....	13
.....	.....	.26	.04	Trace.	.25	4.0	106	.....	.....	14
.....	.....	.24	.06	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	365	.....	.....	289
.....	1.60	.28	.09	.002	.50	7.0	134	26	55.2	45
.....	2.13	.14	.04	Trace.	.25	4.0	138	33	.....	19
.....	1.15	.24	Trace.	.003	.50	3.0	156	48	82.8	41
.....	3.10	.45	.02	.002	.50	6.0	273	47	.....	139
.....	1.80	.32	.03	.002	.125	4.0	163	46	85.6	56
r 17	1.70	.23	.02	.008	.50	4.0	173	46	96.6	45
r 28	1.10	.36	.03	.004	.50	5.0	147	32	117.3	13
3.....	1.10	.29	.11	.002	.50	5.0	149	41	111.8	12
5.....	1.30	.20	.10	.006	.25	4.0	134	38	110.4	.....
r 10	.80	.28	.10	.0125	.50	3.0	143	47	117.3	2
r 28	1.65	.....	.03	.030	Trace.	5.0	159	39	117.3	28
13.....	1.70	.18	.28	.080	2.50	5.0	158	30	117.3	1
16.....	1.35	.12	.08	Trace	2.00	4.5	170	61	117.3	22
22	1.55	.11	.02	.003	.75	5.5	161	40	214.2	0
31.....	2.40	.20	.03	Trace.	1.00	5.0	134	29	106.1	.....
5										
.....	2.75	.31	.10	Trace.	1.00	5.0	120	50	85.8	9
4.....	3.30	.29	.24	Trace.	1.00	5.0	112	25	66.4	33
0.....	1.50	.21	.05	Trace.	1.35	12.0	100	42	65.5	13
8.....	2.75	.30	.09	Trace.	1.75	4.0	.....	.....	78	.....
4.....	1.90	.20	.06	.002	2.00	6.0	.....	.....	70.2	.....
11.....	1.10	.05	.02	Trace.	2.25	7.0	132	47	.....	0
18.....	2.35	.12	.10	.004	2.50	7.0	106	48	106.1	18
25.....	.85	.07	.07	Trace.	2.50	6.0	116	56	100.0	28
.....	1.50	.17	.17	Trace.	2.00	6.0	.....	.....	60.3	.....
.....	1.10	.34	.04	Trace.	2.00	6.5	67	29	59.3	137
.....	.40	.26	.02	Trace.	2.00	5.5	.....	.....	57.3	.....
.....	2.85	.14	.06	Trace.	2.00	6.0	.....	.....	57.3	.....
.....	1.50	.18	.14	Trace.	2.50	7.0	.....	.....	59.0	.....
rage....	1.72	.229	.073	.0054	1.16	5.23	.....	.....	88.98	.....

Comparison of analysis of Potomac water by several investigators.

[Parts per million.]

	Required oxygen.	Nitrogen as—				Chlorine.	Total solids.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
fice, 1904–5.....	1.72	0.229	0.073	.0054	1.16	5.23	146.1
fice, 1897–1900.....	2.56	.111	.0008	Trace.	.639	3.78	126.7
eneral's Office, 1899....	2.10	.150	Trace.	Trace.	1.100	4.00	125.0
ton.....	4.50	.105	.013	.002	.73	2.60	139.0

Mineral analyses of surface waters in Potomac basin.

[Parts per million.]

	North Branch Potomac River above Bayard, Feb. 27, 1905.	Buffalo Creek at mouth, Feb. 27, 1905.	Abram Creek at mouth, Feb. 27, 1905.	Savage River, Feb. 25, 1905.	Georges Creek at mouth, Feb. 25, 1905.	North Branch Potomac River above Savage River, Feb. 25, 1905.	N B P F a n I. Fe 1
SiO_2	6.30	6.10	5.75	9.46	17.40	4.95	
Fe_2O_3, Al_2O_3	5.20	3.19	4.40	6.00	127.60	4.90	
Ca	6.29	8.21	.....	9.65	138.96	10.00	
Mg	1.33	1.62	1.44	1.07	33.66	1.44	
Na	Trace.	5.22	Trace.	Trace.	6.97	Trace.	
K	Trace.	Trace.	Trace.	Trace.	Trace.	None.	
Cl	6.0	9.0	5.0	5.0	17.0	11.0	
SO_4	95.69	5.42	113.65	60.94	577.08	.....	
CO_3	None.	None.	None.	None.	None.	None.	
HCO_3	33.3	27.3	30.3	30.3	None.	36.3	
Quantity analyzed (cubic centimeters)	2,000	2,000	2,000	1,500	1,500	2,000	

	North Branch Potomac River below mill at Luke, Feb. 25, 1905.	North Branch Potomac River between Keyser and Piedmont, Feb. 25, 1905.	North Branch Potomac River above New Creek, Feb. 25, 1905.	Wills Creek above Kreigbaum, Dec. 29, 1904.	Jennings Run at mouth, Dec. 29, 1904.	Braddock Run at Allegheny Grove, Dec. 29, 1904.	W Cre Cu la De
SiO_2	5.00	6.06	5.09	4.67	11.1	5.13	
Fe_2O_3, Al_2O_3	78.92	40.39	26.79	69.84	28.49	2.17	
Ca	2.52	8.45	40.02	22.24	85.49	24.88	
Mg	1.75	4.61	4.07	2.28	1.51	4.53	
Na	.....	4.12	Trace.	6.59	.32	Trace.	
K	.....	Trace.	Trace.	Trace.	1.77	Trace.	
Cl	25.0	10.0	11.0	10.0	15.0	9.0	
SO_4	73.95	14.42	15.93	22.81	274.44	33.41	
CO_3	None.	None.	11.92	None.	None.	None.	
HCO_3	78.7	36.3	39.4	42.4	9.1	54.5	
Quantity analyzed (cubic centimeters)	2,000	1,500	1,000	2,000	2,000	1,500	

	North Branch Potomac River at Cumberland, Dec. 30, 1904.	Potomac River above Pawpaw, Feb. 10, 1905.	Potomac River below Great Cacapon, Feb. 12, 1905.	Potomac River at Opequon Creek, Feb 17, 1905.	Potomac River above Harpers Ferry, July 4, 1904.	North Fork of Shenandoah River above Passage Creek, Feb. 2, 1905.	Pa Cre mo Fe 1
SiO_2	7.31	6.14	8.63	7.47	6.48	6.66	
Fe_2O_3, Al_2O_3	3.52	7.20	43.87	5.66	32.75	94.92	
Ca	38.04	52.33	3.01	47.76	40.26	.38	
Mg	5.52	4.92	4.10	4.78	3.95	9.90	
Na	2.97	2.47	1.94	1.17	1.00	None.	
K	1.19	None.	None.	Trace.	Trace.	None.	
Cl	5.0	8.0	4.0	11.5	5.0	12.5	
SO_4	42.16	140.54	3.95	48.36	18.37	4.71	
CO_3	None.	None.	None.	None.	14.89	None.	
HCO_3	45.4	215.0	106.0	125.7	42.39	202.9	
Quantity analyzed (cubic centimeters)	4,500	1,500	1,900	3,000	5,000	3,000	

Mineral analyses of surface waters in Potomac basin—Continued.

	South River, Jan. 25, 1905.	Elk Run below Elkton, Feb. 4, 1905.	Hawksbill Creek, Jan. 26, 1905.	Hawksbill Creek, Feb. 3, 1905.	Shenandoah River at mouth, July 4, 1904.	Patterson Creek at mouth, Feb. 13, 1905.	South Branch Potomac River at mouth, Feb. 10, 1905.
s	11.37	11.47	14.14	9.44	10.84	10.54	6.13
$)_3$, Al_2O_3	3.60	22.12	11.30	37.95	21.70	7.00	6.00
	33.74	2.77	39.54	3.29	40.52	51.47	51.47
	8.66	4.89	9.11	5.17	5.23	4.48	4.02
	.54	11.35	None.	2.36	1.0	Trace.	.75
	Trace.	2.15	None.	None.	Trace.	Trace.	.35
	10.0	67.0	13.5	21.0	9.0	8.0	7.0
	7.19	2.17	11.3	7.23	6.22	163.0	44.16
	None.	None.	None.	None.	10.43	None.	None.
O_3	115.0	75.7	143.8	117.0	96.90	112.0	816.6
ntity analyzed (cubic centimeters)	3,500	1,500	3,500	5,000	5,000	1,500	1,500

	Great Cacapon River at mouth, Feb. 12, 1905.	Warm Spring Run at mouth, Feb. 10, 1905.	Opequon Creek at Abrams Creek, Feb. 17, 1905.	Antietam Creek at mouth, Jan. 17, 1905.	Catoctin Creek, Md., Jan. 19, 1905.	Monocacy River above Carroll Creek, Jan. 12, 1905.
O_3	32.93	27.60	9.46	4.4	14.80	6.90
$_3O_3$, Al_2O_3	64.51	85.59	8.00	31.70	19.48	2.73
	4.47	5.80	78.64	56.84	3.42	16.30
	3.50	6.30	13.61	1.90	2.80	2.63
	2.00	7.80	4.08	3.88	1.80	5.00
	Trace.	Trace.	.15	4.00	Trace.	2.71
	5.0	6.0	12.0	10.0	7.0	6.0
$)_4$	3.11	6.06	64.92	11.78	5.23	4.46
$)_3$	None.	None.	None.	None.	None.	None.
CO_3	96.9	145 3	308.9	197.7	39.4	51.5
antity analyzed (cubic centimeters)	1,500	1,500	1,500	1,500	2,000	2,000

Monthly analyses of dissolved mineral matter in tap water at Washington, D. C.

[Parts per million.]

	1904.								1905.				Average.
	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Aug.	
$)_3$	3.28	5.87	9.10	4.16	5.10	4.11	3.02	3.00	6.10	6.62	5.41	6.06	5.15
O_3, Al_2O_3	.50	1.00	.93	12.67	0.82	1.36	2.47	2.53	.67	30.19	.96	1.46	4.63
	10.37	13.90	33.93	34.67	53.50	48.51	38.54	54.41	23.17	11.41	20.27	28.61	30.94
	1.87	3.03	8.00	3.68	5.26	8.38	3.99	8.29	2.74	5.07	2.14	2.97	4.62
	3.44	2.88	.91	2.56	3.47	4.17	5.14	3.04	.38	9.47	2.05	.97	3.20
	2.41	4.51	Trace	Trace	Trace	Trace	Trace	Trace	.51	Trace	Trace	Trace	.62
	2.76	5.00	4.5	4.0	4.5	4.5	4.5	5.0	6.5	6.5	6.0	6.5	5 02
	11.01	11.92	9.98	8.96	9.64	11 20	3.30	8.38	4.92	3 06	11.18	10.55	8 68
		None.	5.96	2.98	5.96	7.45	Trace	None.	None.	None.	None.	None.	2.03
O_3		68.13	84.78	84.78	118.1	121.1	136.3	133.1	74.17	112.0	54.3	88.7	97.77
antity (liters)	20	10	10	10	10	10	10	10	20	10	10	10	

Determination of the different forms of carbon dioxide in the tap water at Washington, D.C.

Date.	CO_3 (parts per million).	HCO_3 (parts per million).	CO_2 (cubic centimeters).		
			Bicarbonate.	Excess.	Free.
1904.					
August 29	2.98	84.8	15.5	14.9	None.
September 17	5.96	109.0	19.9	23.1	3.2
September 28	5.96	109.0	19.9	24.2	4.3
October 26	5.96	121.1	22.1	27.9	5.8
November 10	5.96	130.2	23.8	27.9	4.1
December 13	None.	139.3	25.4	39.5	14.1
December 16	None.	142.3	25.9	42.3	16.4
December 22	None.	142.0	26.0	32.0	6.0
December 31	None.	109.0	19.9	26.7	6.8
1905.					
January 5	None.	87.8	16.1	26.6	15.1
January 14	None.	63.6	11.5	16.6	5.1
January 20	None.	69.6	12.7	7.0	None.
January 28	None.	75.7	13.9	3.0	None.
February 4	None.	87.8	16.0	30.1	14.1
February 11	None.	181.7	55.7	18.9	None.
February 18	None.	105.9	19.3	22.2	2.9
February 25	None.	99.9	18.2	18.9	.7

ELATION OF SOILS AND FOREST COVER TO QUALITY AND QUANTITY OF SURFACE WATER IN THE POTOMAC BASIN.

By W. W. ASHE.

EFFECT OF SOILS ON TURBIDITY OF WATER.

GENERAL DISCUSSION.

The turbidity or muddiness of the Potomac River water, which to majority of the users is considered its most objectionable quality, derived from no one section of the basin and from no single geo- ic formation or type of soil, and comes in part from land of gentle dient and in part from sections where the topographic features stronger. The farming land furnishes the largest amount, but all amounts are due to the wash from woodland on certain types soil. Certain parts are washed from roads, and some comes from cutting away of their banks by streams during freshets. The bidity during freshets is unduly increased above the normal by fact that the more rapid current again takes up the sediment posited as silt beds and sand bars at points of slack water during riods of slower flow, and by the additional fact that on very few the tributaries are there flood plains to form natural settling basins some of the heaviest silt.

Turbidity of the Potomac is not a recent phenomenon. The silt d clay which the older geologic formations west of the Blue Ridge ve contributed to the building of the Coastal Plain were washed in ddy streams from their valleys of shale and limestone. The dmont region has also contributed its share. The deep gorges and ines which, starting at the river, ramify through the soft schists, les, and sandstones that form this portion of the Piedmont region, licate that natural erosion of the friable soils has been proceeding a rapid rate.

The fertile red soils are not entirely responsible for the turbidity; broken topography, the long, warm summer, and heavy inter- tent rainfall are also active factors, and when these occur together bidity is an inalienable accompaniment of a rapid stream.

In a humid climate farther north the growing season is short, the nitrifying and oxidizing capacity of the soil lower; humus rapidly accumulates, both in woodland and in tilled land; the porosity of the soil is maintained, and granulation, even in a heavy soil, seems to be almost a natural condition. The heavy humus content, with the concomitant porosity, whether in a forest soil or in tilled land, promotes absorption and retention of rainfall and minimizes erosion.

Similarly, sod, which is maintained with difficulty in the desiccating autumn climate of the South, naturally sets in a cooler climate in ditches, on stream banks, and in waste places, and forms nearly as perfect a protection against erosion as a forest cover. In those sections where thick sod does not form, a forest cover is the best protection against erosion on steep land.

The conditions which surround the upper headwaters of North Branch of Potomac River above Cumberland are largely those which determine the clearness of northern streams; and until it reaches Cumberland it is a clear stream. Below Cumberland there is a rapid change; both the soil and climatic conditions become more favorable for increased muddiness, reaching the optimum conditions just above Washington and in the Shenandoah and Cumberland valleys.

The present turbidity, however, is excessive. The washed-out beds of the smaller streams, extending in places from hill to hill without banks, and the many-gullied and thin-soiled slopes all indicate that erosion is taking place now more rapidly than formerly and that the turbidity is greater. Its further increase from certain sources can be checked, and it can undoubtedly be considerably lessened from other sources, to the general benefit of the valleys, as well as to the improvement of the potability of the water.

While the turbidity is from many different sources, the greater part of it is from the wash from steep or badly tilled cleared land. Where it is the fault of the manner of tillage, more rational cultural methods can eliminate or reduce it. Where it is from the erosion of steep land and can not be prevented by better methods of culture, and it is evident that the amount and rapidity of the erosion are such as to jeopardize the future earning power of the land, this land and other areas of the same character that are yet in timber should be regarded as forest land and nonagricultural. Far higher and more potent reasons than the clarification of the water demand the withdrawal of the land from a use which means its ultimate loss of earning power, to be preserved by applying it to a different use as an active factor in the nation's future wealth.

SOILS EAST OF THE ALLEGHENY FRONT.

SOIL FORMATIONS.

The important soil formations[a] of the Potomac River basin, east the Allegheny Mountains, are the Cecil soils, marked by stiff, avy, usually red subsoils, heterogeneous in texture, underlying re friable and looser surface soils; the Chester series, until recently[b] luded in the Cecil, distinguished by lighter, less coherent, and ually more micaceous soils, which are more subject to erosion than her the Cecil or Penn soils, represented on the Potomac watershed only two soil types, the Chester mica loam and Chester loam; the nn series, dark-red soils and subsoils, more homogeneous in texture an the Cecil soils and resembling them in cohesion, but far less able than the Chester soils; the Hagerstown series, generally avy limestone soils; the yellow shale soils, compact yellow or red- h clays or leachy gravel; the Upshur series, dark-red shallow loams d sandy loams, and the Dekalb series, gray somewhat sandy soils, ually shallow, stony, and coarse grained.

The first five are, as a rule, valley types, and when not on steep pes are generally farmed. The Upshur soils are partly cleared, t are little farmed. The Dekalb series are largely mountain types. ey are but little cleared and where cleared are largely in grass.

The Cecil and Penn soils are largely drained by the streams east of Blue Ridge, only small areas of these types lying on its western e. The other soils very largely lie to the west of the Blue Ridge. e Cecil and Chester soils are responsible for most of the turbidity the Piedmont streams of the South Atlantic States.

The streams east of the Blue Ridge contribute very largely to the bidity of the Potomac, and it is probable that they add a large, ot the largest, part of the coarser silt that is brought down during sons of medium heavy rain, with 1½ to 2 inches of rainfall dis- buted over a period of twenty-four to thirty-six hours. The pre- iling soil types are of the Penn and Cecil series, which are usually sufficient depth for cultivation, but in many of their phases loose d incoherent, and, if denuded, eroding under moderate rains. eir tendency to wash is increased, especially near the river, by ir situation on steep slopes.

CECIL AND CHESTER SOILS.

Cecil silt loam is a gray soil of fine texture derived from the decay partly metamorphosed sandy shales. On surfaces which are at steep it erodes badly, forming deep gullies down to the undecom-

[a] he classification and nomenclature of soils used in this paper are those adopted by the Bureau of ils, Department of Agriculture. In no sense are they geologic, and the names should not be con- with the names of geologic formations.

[b] oil Survey *Field Book*, U. S. Department of Agriculture, 1906, p. 108.

posed rock from which it was formed, and entirely destroying the value of the land for farming purposes. Its composition is such that its washings add a very fine and undesirable matter to the water. The mechanical analyses[a] of this soil made by the Bureau of Soils from a sample 3 miles east of Leesburg, Va., give it the following percentage of silt and clay: Silt (0.05 to 0.005 mm.), 60.06 per cent; clay (0.005 to 0.001 mm.), 22.80 per cent.

Most of the areas of this soil on the basin are badly situated to prevent washing. Some of the largest are on the south side of the river at the mouth of Goose Creek, where the rough topography—the river hills being steep and 200 or more feet high—is unfavorable for clean tillage. Other areas lie on the steep upper slopes of Broad Run and below that stream, all close to the river, and frequently showing, in spite of attempts at careful cultivation, gullying and washing. The agricultural limits of the soil are partly recognized, and less than one-half of these areas are cleared. It does not hold a grazing sod, and when the slope becomes at all steep it ceases to be an agricultural soil and its earning capacity in such situations can be perpetuated only by retaining it in timber. The forests are largely of black oak, chestnut oak, scarlet oak, and pitch pine. Its situation so close to the river and the relatively short distance above the intake of the Washington water supply render the protection of this soil from further erosion important. The humus formed is not deep except in the bottom of the deep hollows, and in spite of it some erosion takes place, the run-off from wooded areas of this soil being slightly turbid.

The Chester mica loam is a loose, incoherent, red soil, derived from mica schist. On steep surfaces it washes badly and considerable soil transportation habitually takes place. On account of its composition, 25 per cent being clay and about 30 per cent fine silt, such washing adds an objectionable element to the water. This soil occurs in small areas along the eastern base of the Catoctin Mountains, in Virginia; in larger areas in the eastern part of Frederick County, Md., on Monocacy River; in Montgomery County, Md., on the upper waters of Seneca Creek; and in the lower portion of Fairfax County, Va. On Seneca Creek it is extensively farmed and contributes much to the objectionable turbidity of that stream. Where level and undulating it does not erode so rapidly, but on steep slopes a great deal of badly gullied land can be seen, and in such situations it ceases to be a farming soil and its preservation is possible only by keeping it in forest. It is not a good grazing soil, becoming too dry in the autumn. The characteristic forest growth on this soil is composed of chestnut and chestnut oak on the better phases, and scarlet oak and pitch or Jersey

[a] Field Operations, 1903, p. 223.

ne on the drier portions, usually with an underwood of mountain urel. The humus varies from good to thin. When this soil is in rest there is little washing. A large area of this type has been ɜared, and much of it has deteriorated appreciably. The roads on is soil wash very badly, often being several feet below the surface vel. The beds of streams also are much washed, and they are often thout banks; turbidity comes from both sources.

The Cecil clay loam is a dark-red soil having an extensive distriıtion on Monocacy River in Adams County, Pa., and Frederick ɔunty, Md., and is extensively cleared and used for farming. Soil ansportation steadily takes place, and while gullies are not formed, ɜere is a constant and uniform removal of soil from even moderate ɔpes. Fortunately, it is in few places deeply dissected, and careful ethods of tillage can do much to reduce turbidity from these soils. grasses only moderately well. The remaining forest is of oak and ckory and forms a sufficient humus to insure protection.

The Chester loam and Cecil clay form large areas on Monocacy iver in Carroll and Frederick counties, Md., on Seneca Creek in ontgomery County, Md., and on Broad Run and other small reams in Loudoun and Fairfax counties, Va., between Broad un and Great Falls. They also form extensive areas in upper oudoun County and in western Frederick County, on the two atoctin creeks and at the head of Goose Creek. These soils are ɜrived largely from the Catoctin schist and granite and from other ica schists. They are light brown or red in color, deep, and rather ɔrous, but the lighter phases are often incoherent and when dry uch resemble the mica loams in texture and behavior toward ater. While they form large areas of productive and well-farmed nd, considerable washing takes place, especially in the spring, when ıw-plowed surfaces, already saturated, are exposed to heavy rains, ıd this washing increases with the gradient. The surface of these ɔils, especially near the mountains and along the river, is deeply ırved into high, rolling-topped hills, the stream valleys in many places ɜing 200 to 300 feet deep. Only an insignificant portion of these ɔils remains uncleared, and while they generally grass well, there on steep land considerable gullying. In Virginia, except on Catocn Creek, these lands are mostly held in large estates and are used ɔr grazing, some of the sod not having been turned for sixty years. ı Maryland they are divided into small farms and tillage is the rule. oads wash badly on these soils, and the beds of the smaller streams, ɜpecially on the Maryland areas, are badly eroded and much enlarged, ıe banks being steep, naked, and cut back to the base of the hill on ther side. On account of the fertility of these soils, clearings have ɜen extended to slopes which are much too steep even for grazing,

and several thousand acres of such slopes lying in deep hollows can have the soil retained only by reforesting. The mechanical analyses of the Bureau of Soils show that from 50 to 70 per cent of these soils consist of clay and fine silt. On account of their extensive area and situation on steep slopes close to the river and only a short distance above the Great Falls intake, they contribute much to the turbidity of the Washington water. The forests are of oak and hickory on the heavier phases; chestnut on the lighter. Humus on both types is good, and where forested there is no appreciable erosion, except on the steepest slopes during very heavy rains.

PENN SOILS.

The Penn soils cover extensive areas in the valley of Monocacy River and also on the lower part of Goose Creek. The heavier members have usually a rolling surface, and there is sufficient cohesion to prevent excessive erosion, which is also reduced by the fact that the soils grass very well and are excellently tilled. Many of the areas lie close to the larger streams, and some steep banks have been cleared which would have held better in timber. Roads wash somewhat; stream beds only slightly. These soils are largely cleared. The forests were of oak, hickory, walnut, and ash.

The Penn shale loam, on the other hand, which is a dark-red soil, extending southwest from Gettysburg, Pa., in a broad belt, undergoes continuous erosion. A great portion of it is gently rolling, but near the larger streams it is much broken, and since it does not grass well much erosion takes place from cultivated land in such situations. Erosion is usually in the manner of uniform soil transportation, resulting in the gradual thinning of the entire slope and not in the formation of gullies. Some of the cleared slopes are too steep to justify tillage. This soil has from 50 to 80 per cent of fine silt and clay, and undoubtedly the steeper gradients contribute to the turbidity of the Potomac. The smaller stream valleys are shallow and broad, and there is little erosion from them. Pitch and Jersey pines, with scarlet, black, and chestnut oaks, and in some places chestnut, form the forest. There is considerable old field pine. This type of forest forms only a thin humus, but there seems to be very little washing from beneath it. The greater part of this soil is cleared.

LIMESTONE SOILS.

The limestone soils of the Hagerstown series of the classification of the Bureau of Soils constitute the most sought for, best-farmed, and highest-priced soils of the Potomac basin. Together with some *calcareous* and argillaceous shale soils they form more than three-*fourths* of the cleared land in the valley of Virginia and the Cumber-

land Valley. The Hagerstown clay is a residual soil from the weathering of the purer limestones, and represents the less soluble portion of the rock. The loamy and sandy phases are from limestone that is less pure and has more quartz veins in it, and more and coarser insoluble residue has been left to form the soil; or they are derived from shales. On gentle slopes there is very little erosion of these soils. There is more, however, on the heavy types, where the compact texture of the clay greatly impedes absorption, than on the looser, more porous types. On steeper slopes there is, at least on the heavier soils, continual though often slight transportation, which reaches its minimum when the soil is in permanent sod or in timber. On account of the fertility of these soils, and especially their high productivity in wheat, they are in constant cultivation under a short rotation, including both corn and wheat as well as hay.

While the gradients are usually slight on these soils in the Cumberland Valley, in the valley of Virginia, and in the smaller areas on Monocacy River in Adams County, Pa., and Frederick County, Md., yet there are local areas, especially contiguous to the larger streams, where the slopes are very steep, and many badly eroded fields are to be seen in such places. Even when deep plowing and careful tillage has prevented excessive gullying on steep slopes, rapid soil transportation takes place, though it is largely distributed over the entire surface, and the soil after each heavy rain is left thinner than before, and this unchecked waste portends its ultimate depauperation.[a] In fact, this has already taken place on extensive areas of limestone soil, which are closely similar to the heavier types of the Hagerstown soils. These are limestone soils in the Martin Mountains in Bedford county, Pa., in the Patterson Creek Mountains in Grant and Mineral counties, W. Va., in a portion of the Tonoloway Ridge in Hampshire County, W. Va., in the elevated valleys of the Knobly Mountains, and in the high steep limestone slopes which lie just beneath the crest of North Fork Mountain and in nearly similar situations on South Fork Mountain just east of Franklin, Pendleton County, W. Va. There are, moreover, many fields in each of the soil areas just mentioned so badly gullied that grassing has become impossible. The soils have become so shallow, and transportation of soil from the raw surfaces takes place so constantly, that the blue-grass sod, which is the natural covering of these lands, can not spread and hold, and reforestation will be the only means of again giving them a permanent earning power. The difficulty with soils of this character is that they can not be manured, on account of the impossibility of getting a wagon and team on the steep

[a] In the southern Piedmont region such long-continued partial erosion gives rise to sandy surface soils underlain by heavy subsoils.

slopes, and every crop of grain or grass which is removed robs them of fertility, while nothing except mineral fertilizers of the acid-phosphate type are added to them in compensation. When these soils are kept in grass there is very little washing, but on account of their productivity, as compared with either the shale soil of the valleys or the surrounding thin soils of the sandstones, their cultivation by the small landholder is a necessity until their final ruin precludes cultivation of any kind.

The well-known case of the soil-denuded limestones of the Alps of Bosnia and southern Austria, the Karst region, is being reproduced here under almost the same conditions. Both are regions of steep slopes and naturally rather shallow but very fertile limestone soils, which have by the exhaustion of humus through constant tillage lost their granulation and had their absorption capacity for rainfall so reduced that extensive washing has taken place, leading to the destruction of the agricultural value of the soils. The highest earning power which such soils now have is in timber production. Their natural forests are of hickory, white oak, walnut, locust, red oak, and, on dry knolls, black oak, and since all these except the black oak yield high-priced woods, and rapid growth is made by timber on the limestone, reforestation could be regarded as a financially profitable undertaking. When forested there is a heavy humus on even the steepest limestone land and a heavy undergrowth of weeds, bushes, and vines. The thick humus not only holds a great deal of water, but the heavy clays of the limestone have a higher capacity for absorption than any other soil on the Potomac, and the humus allows those soils to become fully saturated. On account of the heavy humus there is almost no turbid run-off from even the steepest limestone soils when in timber. In addition to the areas already mentioned, other heavy limestone soils cover several thousand acres in Highland County, Va., between Monterey and Hightown, and areas of less extent in the "Hunting Ground" in Pendleton County, W. Va., on the upper waters of North Fork of the Potomac; on Evitts Creek, Bedford County, Pa., in the Little Cumberland Valley; and in the Cove Valley about McConnellsburg, Fulton County, Pa. In these areas the topography is rolling or the hills have long, moderately gentle slopes, except along the larger streams, where the slopes are steeper, as they are in the valley of Virginia, and erosion takes place in the same manner and under the same conditions as on the Hagerstown soils farther east. The soils are worked in short rotations, more than two-thirds of the land being habitually in tillage and the rest in grass.

Mechanical analyses[a] of the Hagerstown clay, which will cover the composition of the heaviest limestone soils in the Potomac basin,

[a] Field Operations Bureau of Soils, 1903, p. 212.

to contain from 34 to 38 per cent of clay less than 0.005 size, and from 40 to 46 per cent of fine silt between 0.05 and m. More than three-fourths of its composition is matter tly divided to be transported on the most quietly moving of Potomac River, and practically none of the wash from nds settles above the Great Falls intake.

nore sandy members of the calcareous soils show a lower per- of clay content and a higher of silt, the clay forming from 14 r cent,[a] while the silt forms from 31 to 50 per cent. While tive proportions of the light and heavy soils are not known, one-half of the limestone soils are referable to the heavy s. The above analyses of texture are of the top soils. On led land on the mountains, where gullying is taking place, the l is largely from the subsoil, and this shows a far higher pro- of fine, transportable clay, the amount being from 50 to 63 [a] of the entire soil. The proportion of fine silt, however, is smaller.

at is the erosion from steep limestone lands that during heavy storms the turbid streams which bear their wash strongly he argillaceous odor characteristic of a freshly cut surface of lay. This is especially noticeable with the water of Town hich bears the wash from Martin Mountain; Big Cove Creek, as the wash from the limestones in the vicinity of McCon- g; Conococheague Creek, which drains the Cumberland Val- l the two branches of Shenandoah River, which drain the val- irginia and the Page Valley; and there are other streams in is probably at times as noticeable as in these.

lition to the wash from the agricultural lands a small amount ace from the roads, but most of the roads through the lime- surfaced with crushed stone and have been graded or washed l before being surfaced.

the banks of streams the limestone soils grass well, and there light erosion of banks on any of the smaller streams.

vident, on account of the constant erosion that takes place on stone soils, which rapidly increases with the gradient, and e proportions of transportable clay that these soils contain, y contribute a large proportion of the turbidity to the river, even a larger proportion than the soils of the Cecil and Ches- os; but with this difference in respect to the Washington water hat local showers on the Cecil soils, on account of their near- he Washington intake, and especially rains on the lower part eacy River and on Seneca Creek, which empty into the Poto- the same side on which the intake is situated, produce high

[a] Field Operations Bureau of Soils, 1903, pp. 214, 215.

turbidity for short periods, especially during summer thunderstorms. The turbidity produced by similar storms higher up on the watershed is largely reduced by dilution, opportunity being given for thorough mixing with the water across the entire channel of the river, and also by distribution, a portion being carried far ahead in the main current of the river, while those parts which mixed with the water near the bank, where friction is greatest, get farther and farther behind. The total effect on the water by the time the intake is reached is a slight rise in turbidity, which is distributed, however, over a day's flow or more. Such local rains on the Cecil soils in Maryland, as has been explained, cause high turbidity along the north bank, and there is neither time for further dilution nor opportunity for distribution. The rapidity and unexpectedness with which this condition is produced occasionally cause a considerable amount of highly turbid water to enter the reservoirs which supply Washington.

About one-tenth of the mountain land between the Allegheny Front and Shenandoah Mountain is limestone or limestone shales. The largest part of the land lies in Highland County, Va., and Pendleton, Grant, Hardy, and Mineral counties, W. Va. The average slope of this land is more than 1 foot in 5. Probably one-half of it is at present cleared, and the rest is being cleared rapidly. The limestone soils, including both the valley and mountain lands, constitute about one-sixth of the total area of the Potomac River basin, or about 2,000 square miles.

There are very few springs on the limestone soils, in spite of their very great water-storage capacity, but such as there are show great constancy and boldness. Many of them are undoubtedly streams which permeate fissures or caverns in the limestone.

SHALE SOILS.

Shale soils are of two different series—those derived from massive or fissile argillaceous shales, known throughout the basin as "yellow-slate soils," largely the product of weathering of the Romney shale and the shales of the Jennings formation; and those derived from the weathering of the sandy shales and sandstone of the Hampshire formation, which are known as "red-slate soils." The yellow-slate soils are soft, erode rapidly, and constitute essentially a valley type of soil; the red-slate soils form plateaus and low mountains.

The yellow-shale soils are extensively distributed, and some of their phases are the source of considerable turbidity. The first of the two extreme types is the typical "slate soil," largely formed of small sharp-angled pieces of argillaceous shale. Occasionally it is called gravelly soil. Only a small amount of fine earth is associated with it. It is extremely porous and leachy, and transportation takes place so

idly that very little finely divided earth accumulates. It is essenly a thin, light soil, and its condition is due not only to the fact that shale decomposes slowly, but also to the erosion of the finer terial proceeding practically at the same rate at which it is formed, to its situation on steep slopes high above the base-level of erosion; it is in places the wornout shale clay of the type described in the ct paragraph, from which the fine soil has been removed by washing en cultivated.

The second type embraces yellow-shale clay and its loamy phases. is the residual product from the weathering of the argillaceous and derately sandy shales, where there has been but little soil transtation. On broad flats near the heads of streams and where the lley hills have been eroded nearly to stream level, soil has accumued to the depth of several feet, but as the slope becomes steeper the l rapidly becomes shallower and "slate" chips more abundant, a pid transition taking place with increased slope into the "slate-soil" pe. These soils do not hold grass well except at high elevations, and nstant tillage rapidly changes their character and lessens their rning value, as the fine soil is eroded. Above 1,500 feet altitude and cool situations along moist slopes sheltered in part from the heat of e sun, especially on the heavier and more calcareous shales of the ckwood formation, and some in the Romney formation, a permant grazing sod can be maintained. In other situations the grass s in a few years and a scant growth of pennyroyal and spring and rly summer weeds takes its place. When the shale soils are on high pes the characteristic topographic features are the small size of the ls and the number and depth of the fissures which indent them, the face features being in strong contrast to the rolling summits and ad, flat slopes, even where steep, which mark the limestone. This oken surface of the shale hills is another drawback to general farm; on them, making the fields small and their cultivation difficult, and using some inequality in the maturing of the crops. A crop makes the typical leachy slate soil only when there is a wet growing season, l for this reason wheat, growing largely during the wet spring, is re successfully raised on it than corn. The soils are not, however, apted to farming, and large areas which have been cleared are ned out nominally as pasture, but in fact are practically waste. here the soils are deep and the slopes gentle the soils are very proctive in corn, hay, small grain, and apples.

Mechanical analyses of these soils show that the earthy portion cludes from 22 to 40 per cent of clay. They are responsible for a nsiderable portion of the turbidity of South Branch of the Potomac, d of Patterson, Back, Sleepy, Sideling Hill, Great Tonoloway, and cking creeks. While a large part of the wash comes from clear d, the washing of the banks of small streams, especially when

trees and bushes have been entirely cut off, is a notable feature. Some also comes from roads, which are inclined to wash, especially on the compact clay soils. A small amount comes from the woodland, as the streams which drain forested watersheds becomes conspicuously clouded during heavy and especially prolonged rains.

The forests on the shale soils vary with the drainage of the soil. Where the topography is gentle and the clay soil is deep, white oak, a small amount of chestnut oak, and in the hollows red oak form the timber, the white oak always being the aggressive species. With increased dryness, due either to the thinness of the decomposed clay soil or to greater inclination of slope, Jersey pine and chestnut oak become the dominant species, white oak being of minor importance. A moderate humus accumulates under the red and white oaks, but elsewhere the humus is very light on this soil. The springs in the shales are numerous, but small and irregular in their flow, many of them going dry during the summer and autumn. Probably one-half of the total area of shale soils has been cleared, but a large part of it is idle. On steep slopes and in its leachy phases the shale soils are not agricultural, and while they have a low earning power in forest they are best preserved by being wooded. On gentle slopes the shale soils can be made highly productive. A feature about them is the rapidity with which the bits of shale disintegrate when exposed to the weather; for this reason these soils can not be completely exhausted.

The red shales and sandstones of the Hampshire formation west of Shenandoah Mountain yield soils which are referred by the Bureau of Soils to the Upshur series. On the Potomac watershed the country rock of this formation is largely a sandy dark-red shale. It occurs usually in elevated valleys, as Long Hollow, in Washington County, Md., or in broken plateaus, as the "Levels," in Hampshire County, W. Va., and Timber Ridge, in Fulton County, Pa.; or it forms low, flat-topped mountains, as Town Hill and the foothills of Sideling Hill, in West Virginia, Maryland, and Pennsylvania. The larger streams have in most places cut deep gorges through it, with steep, precipitous sides. The gently rolling surface, which is generally farmed, is in sharp contrast with the much broken surface of the yellow shales, and when the two occur side by side the red shale is usually at a higher elevation. The soils derived from it east of the Allegheny Front are usually loams and sandy loams, in few places passing into stiff phases; they are shallow, rarely more than 2 feet deep, with much broken shale and bits of sandstone disseminated through them, and dark-red or chocolate in color. The porosity is excellent and, the underlying shale being much fissured, there is comparatively little erosion except on steep slopes, where considerable sand and even coarse gravel is transported. The sandy members are too light, thin, and leachy for successful production of corn and wheat, the staple crops of the region,

d large areas which have been cleared, amounting probably to ore than 10,000 acres, have been abandoned and are offered for sale prices between $5 and $8 an acre. Other extensive areas, which e held in connection with operated farms as pasture land, are prac-ally waste. The lighter phases will not hold a grazing sod, and hay ass lasts only a season or two on it. Except on the heavier phases or e most gentle slopes, as about Three Churches and the middle portion Timber Ridge, this soil yields, if worked in grain and grass, only e scantiest living to the tiller. Under the current system of tillage is not a productive general farming soil. Recently, however, exten-re areas of this soil on the "Levels" and elsewhere have been planted peaches, to which it is well adapted. The soil can be used profit-ly for this purpose and similar intensive farming, to which it seems be adapted, only where transportation is available, which excludes present the largest areas. It is, when shallow and on steep slopes, forest soil and must ultimately be regarded as such unless planted in aches, small fruit, or truck. More than one-half of this soil is yet woodland. As would be expected from its lightness, the timber neither tall nor the stand heavy. On the heavier members short-af pine, black oak, and pignut hickory form the growth, which anges to scarlet oak and pitch pine as the soil becomes more sandy id shallower. The humus is light.

Not so much turbidity originates from these soils as would be sup-osed from their red color, although the run-off from tilled land is ways muddy. The waters which come from wooded areas, how-ver, seem always to be clear.

SANDSTONE SOILS.

Sandstones form the greater part of the mountains, the limestones id smaller areas of shale and granite forming the rest; and since the ndstone yields a sandy soil, this is the prevailing and character-tic mountain type. The soils of the sandstone, forming the sandy embers of the Dekalb series, are all very sandy, some very shallow, id most of them stony, their final form being determined by the rdness of the rock from which they originated and the steepness the slope on which they are formed.

The deepest sandy soils and those best suited to tillage come from e "Monterey sandstone" and the sandy beds of the Jennings and ampshire formations. These are loams and sandy loams, and hile they are deep in but few places they are usually found at the gher elevations and are well supplied with organic matter. Even the case of some of these formations which rapidly decompose, ere is, where they lie on steep slopes, constant soil transportation, id the residual soil is shallow. On account of this constant loss there

is around the base of many of the sandstone mountains a heavy talus of sand washed from the heights, forming a mantle over the valley formations of shale and limestone. This is especially noticeable in the Cumberland Valley, in the valley of Virginia, and, to a less extent, elsewhere.

The more indurated sandstones and the quartzite yield only the thinnest kinds of mountain soils, which are strewn with large and angular fragments of stone. Such stony land is suitable only for forest growth, and no attempt has yet been made to clear it. At least one-half of the mountain land east of the Allegheny Mountains is of this character. The sandy soils of the valleys, as well as those of the level benches of the mountains, except where light and leachy, are farming and fruit-raising soils. Considerable areas of sandy land on the mountains, with soil of some depth, were cleared originally for grass land. It is well suited for sod land, and so long as the turf is not turned it holds very well, its porosity being sufficient to absorb heavy rains readily without washing. When cultivated, especially in corn, it washes very badly; less so when in oats and buckwheat.

While these soils contribute very little to the turbidity of the river, their preservation on the mountains is necessary on other grounds. They and the underlying sandstone, which is in most places well fissured, form the natural reservoirs at the head of nearly all the streams of the Potomac basin. The springs from the sandstone are numerous and constant in their flow, though few of them have the volume and boldness of the limestone springs.

The forests on the sandy soils vary widely in composition and quality, according to the depth of the soil, its drainage, and the aspect. Where the soil is deep and mellow, especially at high elevations or on cool slopes, chestnut and red oak are the characteristic trees, and the humus naturally formed is excellent. In somewhat drier situations white oak is the dominant tree, chestnut oak also becoming abundant, the proportion of the latter increasing with better drainage. The humus becomes thinner as the amount of chestnut oak increases. On cool western slopes, especially in elevated valleys, white pine was a factor in the original growth, but very few trees are now seen, even of young growth. On ridges, especially those that are warm and sunny, pitch and table-mountain pine form groves in many places, almost unmixed with other trees, and in such groves the humus is very thin and poor.

SOILS WEST OF THE ALLEGHENY FRONT.

The soils of the Allegheny Mountains are loams and sandy loams from conglomerates, sandstone, and sandy shales, with smaller areas of clay from more argillaceous shales and from limestone. They are generally gray or yellow, in a few places red or brown, and for the most

art are stony. Large areas are so thin soiled and stony as to be ntirely worthless for agriculture of any kind. These include espeially the soils from the harder conglomerates and sandstone of the lackwater and Pocono formations and the sandstone of the Bayard ormation. These are extensively developed on Spruce Mountain, long Backbone, Savage, and Dans mountains, and on Stony River, here many acres at some places are covered with large angular tones, such places being locally known as rock bars.

The humus content of the soil is large for the several reasons which ave been pointed out, and their absorptive capacity for water is high. he humus, as well as the general looseness, permits rapid percolation f water through the soil to the subsoil. Unless subject to clean tilge on the slopes there is very little erosion of cleared land. Fields ere seen, however, on Wills Creek and on Georges Creek, which from ie cultivation of corn or potatoes had washed badly and are now too in to form a good sod. On the slopes of Red Oak Mountain also, and ong the Allegheny Mountain farther north, the grazing land on the eep southern slopes has become thin and the sod is scant. Some of ie clearings, however, are old, situated along the early pikes and ails which crossed the Allegheny Mountains to the fertile lands of ie Ohio Valley. They clearly indicate, though, that much of this nd which grows well when fresh gradually becomes exhausted even i sod on the steep slopes and must eventually again be timbered to old the soil.

Very little turbidity comes from North Branch of Potomac River bove Cumberland, and the same is true of the headwaters of Wills reek, in Somerset County, Pa., and of Seneca Creek, Laurel Fork, nd the intermediate streams in Pendleton County, W. Va. Only the eaviest summer rains, or spring rains after the loosening of fall-lowed ground by frost, cause evident washing of farmed land, except n the steepest slopes. In spite of the fact that so large a part of the leared land is in sod, the number and constancy of the springs are oteworthy.

The forests in the Alleghenies vary widely in composition; chestnut, ed oak, and chestnut oak are the prevailing species in the warmer and rier situations. The chestnut forms a good humus, and the quantity f humus is largely determined by the proportion of this tree.

On northern slopes and in the moister situations birch, sugar naple, basswood, and beech form most of the timber, while hemlock ccurs with these in many of the ravines. This type of forest occurs n many places on very rough and stony land. The humus is very eep, having accumulated locally to a depth of 8 to 10 inches. Above 4,000 feet elevation, on the headwaters of Stony River, Difficult Creek, nd Buffalo Creek, in Grant County, and on Seneca Creek and Laurel ork, in Pendleton County, W. Va., the forests are largely of spruce.

The soil is of the thinnest character, much of it only beds of stone. In forest which has been unlumbered or unburnt the moss and humus are deep and largely replace the soil for supplying the necessary moisture. There is no discernible erosion of the forest soils where the humus has not been destroyed or lessened. The smaller streams are at times discolored by the leaching of the humus, but to an insignificant degree.

More than one-half of the area of the Allegheny Mountains is forest covered, including nearly all of the steepest slopes.

It is evident that the soils which most largely contribute to the turbidity of Potomac River are those that are most valuable for farming, which are largely cleared. Considerable forest, however, is yet situated on the steeper slopes of some of these soils, especially on certain members of the Cecil series and on much of the limestone on the mountains west of North Mountain. When these areas are cleared the wash from them will augment the already high turbidity of the river. As a matter of civic policy it would be advisable to retain these lands in forest and to reforest extensive areas of similar soils which have been pauperized by erosion incidental to culture or whose permanence is threatened by tillage, since the erosion from them when in forest is insignificant.

EROSION OF FARM LAND.

The primary cause of erosion is the failure of the soil to absorb the rain water which falls upon it. If the rainfall is all absorbed, as by a coarse, sandy soil, there is no run-off and no erosion. As the soil becomes finer in texture, more compact, and correspondingly less pervious, the rain is not absorbed as fast as it falls, and the very smallness of the grains which form the soil facilitates its transportation whenever the attitudinal factors are favorable. The impact of the raindrops loosens the fine particles of soil, and unless absorption takes place the drops gather into small streams and rivulets, transporting with them, by a system of natural elutriation, the finest particles of soil and leaving behind the larger and heavier grains. At first this is entirely due to the hydraulic action of the impinging raindrops, but no sooner do the rivulets gather power, either by the added volume of water or by increased gradient, than they likewise begin cutting loose and transporting the soil. The eroding and transporting action of water is increased by the increase in its volume; it is also increased four times by doubling the gradient. For this reason the steepest land erodes most easily, and since the slope of a rain-formed hill is an ogee and steepest in the middle the most rapid erosion takes place on the middle slope, while the heaviest transported material is deposited by the slackened current on the more gently sloping base.

The capacity of a stiff soil for water is in practice 35 to 50 per cent f its volume, or for ordinary farmed soils 4 to 5 inches of rainfall to ıe surface foot. In spite of this capacity, the greater part of a heavy ıower will usually not be absorbed. The coarse structure of a sandy ›il permits the rainfall to be absorbed as rapidly as it falls. In a clay ›il, unless in a high state of tilth, the pores are smaller and there is ›ss open cellular communication between them, and absorption must ırgely take place through cracks, worm holes, and root holes, and 'hen there are few of these absorption is largely retarded until the air an be expelled. In the extreme case, that of a raw clay soil with its urface puddled by a previous heavy rain, the result is, as King[a] points ut, "that when a heavy rain falls, the close structure and feeble ranulation result in the surface pores of the soil becoming so quickly losed that the soil air has little opportunity to escape, and yet only o fast as it does escape can rain enter the soil, and hence during heavy ains the water accumulates quickly and extensively upon the surface."

The greater portion of the tilled soils of the Potomac basin, espeially of the lower part, are of heavy type and close texture, and the un-off from them indicates failure to absorb. But were they well ranulated and in good tilth they, as well as the more permeable andy soils, could readily absorb, without undue accumulation of urface water, a much heavier rain than commonly falls at one time ın the Potomac basin.

The porous condition or granulation of a heavy soil necessary to ffect absorption is best procured by the addition of humus.

There is over a greater portion of the tilled area a deficiency in the ırganic content or humus. The soils ot the great valley and the egion to the east lie well within the southern field of long, hot sumners and heavy, irregularly distributed rainfall. The organic conent of typical tilled soils of this region, as given by the Bureau of ›oils, is for the Iredell clay loam, 1.43 per cent; Penn loam, 1.70 per ent; Penn clay, 1.92 to 3.04 per cent; Hagerstown clay, 1.51 per ent; Cecil loam, 1.07 per cent; Cecil clay, 1.63 per cent.[b] These re from typical areas in Virginia, West Virginia, and Maryland, in a ell-farmed section, and without doubt adequately represent the umous content of these and similar soils throughout the lower culti'ated portion of the Potomac River basin.

For the same or similar soils in the more southern Atlantic States, he organic matter is given[c] as from 5 to 7 per cent for the Cecil clay, .4 to 4 per cent for the Cecil sandy loam, and 4.15 to 4.75 for the redell clay, and it is recognized that even these large amounts are enerally too small[d] to maintain soils in that latitude in good tilth nd sufficiently porous and strongly granulated to prevent washing.

[a] Yearbook U. S. Dept. Agric., 1903, p. 164.
[b] Field Operations Bureau of Soils, 1903, pp. 210 et seq.
[c] Idem, 1901, pp. 280 et seq.
[d] Idem, 1901, p. 281; Yearbook U. S. Dept. Agric., 1903, p. 168.

The growing season in the lower part of the Potomac basin and longer than in the basin of the Susquehanna and t streams to the northeast. Except near the coast, where the humidity is high; on certain types of soil, which are very well to grass; and at high elevations, a permanent sod is with maintained or even established. Many of the soils have hig ing power, and humus, either in the shape of leaf mold in th as manure in farming land, or litter in grass land, is rapidly The result is that a low soil porosity is maintained, with smal tive capacity, saturation quickly taking place and the heav from the steep slopes causing erosion.

Spillman[a] has shown in actual practice that the large in the organic content of a yellow-shale soil in eastern Penn produced a soil structure more largely independent of weath tions than any soil he had ever seen. "Torrential rains ar up," he says, "in a very short time, so that the soil may be after a rain much sooner than that of adjacent forms."

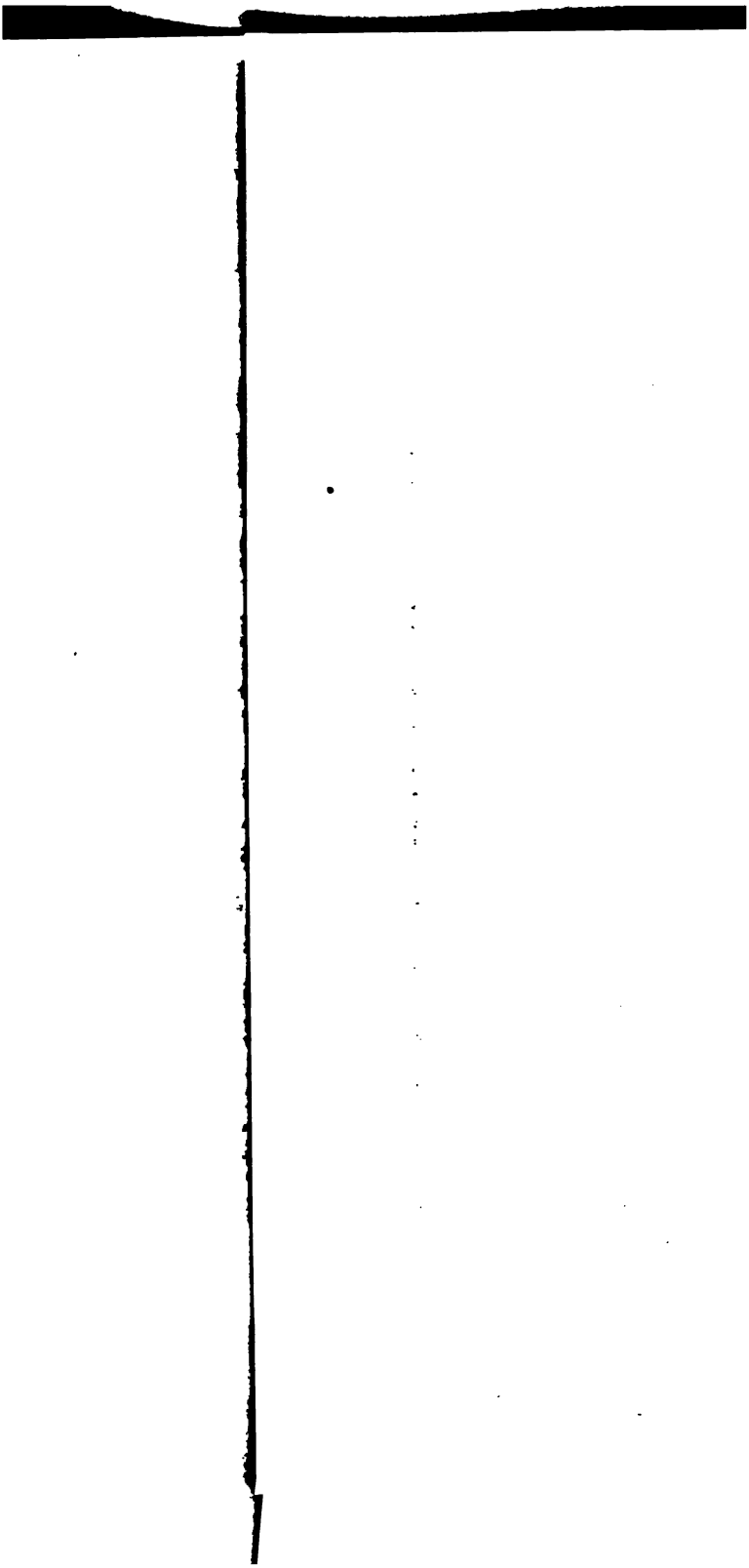
On account of their inability to absorb the necessary moisture content of the heavy clays is often insufficient in the for the proper maturing of the corn crop and causes the grass badly."

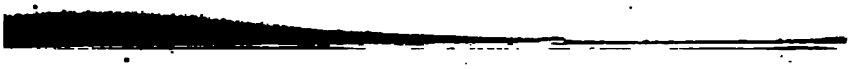
On clay soils, such as the heavy phases of the limestone, ti age also increases the thickness of the permeable layer of top its water-storage capacity. Such drainage would undoub beneficial over a large area of the nearly level or gently roll lands of the limestone, shale, and Penn series in lessening from saturated soils.

The run-off can also be reduced by terracing, which is es adapted to the deep-soiled Penn, Cecil, and Chester series eas Blue Ridge and to the shale soils west of it. This permits the ab and the subsoil storage of the heavy spring and summer rain are so badly needed for plant growth and which are so largely the crop by the run-off. Terracing has been done, in isolate in more southern States, and the increased yield and greater im from drought have more than compensated for the reduced a increased cost of tillage.

Another element in the run-off from farming land which is important as the loss of the water is the loss of the solid elements which form the turbidity as well as the soluble matte is washed off. Mr. Outwater states in another part of this that the soluble matter removed, if derived largely from the tural land, amounts to about 400 pounds per acre per year, plant food in it is about equal to that removed by a crop. W soluble material lost by leaching is replaced with about th

[a] Yearbook U. S. Dept. Agric., 1903, p. 363.





lity as it is removed, the fine particles of silt and clay are replaced slowly. This fine solid matter represents the most valuable ion of the mineral soil on account of its favorable influence on retention of soil moisture and the large surface it offers for root rption. This indicates the necessity from an agricultural standt of storing in the soil the heavy spring and summer rains, that vater may be available for the growing crops and that at the same the fertility of the soil may be maintained by retaining in it the and clay which form the turbidity and the soluble plant food, h is also washed away.

EFFECT OF FOREST COVER ON STREAM FLOW.

EXTENT AND INFLUENCE OF FOREST COVER.

iginally the greater portion of the Potomac basin was wooded, ough the Indians kept much of the Shenandoah and Cumberland ys burned off, as well as certain areas on Monocacy River in ms County, Pa., which even now, on account of this, are known he "Barrens," and smaller areas elsewhere, as at Petersburg, it County, W. Va., and below Moorefield, Hardy County, W. Va. also probable that they regularly burned over portions of the ntains to facilitate hunting, although they do not seem to have the timber suppressed, as was the case in the "Barrens" and vhere in the valleys.

oodland at present covers about one-third of the area of the n. (Pl. X.) It has been very largely removed from the Great Valfrom the Blue Ridge and Catoctin Mountains, and from the Piedt area east of the Blue Ridge. The Shenandoah and Tuscarora ntains are yet well wooded, and there is a more or less continuous of forest on the upper slopes of many of the Appalachian ridges. laces it is continuous for several miles and will cover a great porof the slope; elsewhere it is a very narrow strip along the rocky , or it is entirely segmented into wood lots and covers less than fourth of the mountain slope.

the Allegheny Mountains the forest covers most of the very stony rough land and many of the steep slopes, especially in Maryland West Virginia; but in Somerset County, Pa., large areas of even, land have been cleared and put into grass, and there are no nsive bodies of forest. From this it is evident that the forests not yet been cleared from a large part of the steep land of the n, and the facts as brought out go to show that they are sufficient xtent to play an important rôle in connection with the quality ie Potomac water, although their influence is not as potent as ierly and must continue to decrease as their area becomes smaller. forests are influential in improving the potability of the Potomac

water in three ways: They prevent greater erosion from certain soil types on steep slopes which are yet partly in forest and which wash badly when deforested, and lessen in this way the very high turbidity of the water. They maintain the volume, already very low, of the summer and autumn run-off, which by dilution adds to the real purity of the water, although this is of relatively slight value. They also steady and equalize the flow of the smaller streams and lessen the erosion of their banks.

The water of the smaller streams which flow from forest-covered mountain watersheds is clear and pure. The water of such mountain streams is being used by several towns in the Potomac basin, which obtain their water supply from streams in the Pennsylvania forest reserves, this water being less open to pollution than that of springs and wells. The protection of such forested watersheds in other States than Pennsylvania, to insure their permanence and the general utilization of these streams in place of springs and wells, which are now in general use, or in place of the polluted river water which is used by Cumberland, will, by furnishing a pure supply, largely eliminate these towns as foci of infection of typhoid fever and other water-borne diseases.

One of the tributaries of the Potomac, Great Cacapon River, affords clear and reasonably pure water which would be sufficient for the requirements of Washington, D. C. It drains a valley whose soils are, for the most part, loam and sandy loam, largely nonagricultural and forest covered. Three small villages are the chief sources of contamination. Its distance, 117 miles above the Great Falls intake, is probably too great to render it available as a present source of supply.

There is, as has been pointed out, room for a large storage of storm water in farming soils, and more rational farming methods must ultimately lead to this. The effect of such storage would be reflected in a diminished run-off of flood water, especially of heavy midsummer rains. Little of the water thus accumulated would normally pass off as seepage to spring and river flow. The improved growth of the crops would utilize such stored water, and, given a more constant and available amount of soil moisture, two crops a year would be the rule and not the exception as at present over much of the warmer part of the basin, and in place of the crops transpiring from 4 to 6 inches of the rainfall, as at present, they would use about double that amount.

Any additional storage, either transient, tending to prolong or distribute a flood crest, or deep seated, tending to increase the amount of the dry-season flow, can be secured only in the forest soil. Storage in forest soil, except in sandy phases, takes place very largely through the medium of humus. The amount of water which is actually retained by a thin humus is small, in fact, a thin humus is usually

ır more litter than humus and has a very low retentive capacity; ut the chief functions of humus, except where it has accumulated to great depth, are (1) to maintain the volume and depth of the soil y preventing erosion; (2) to secure the porosity of the soil; (3) to romote the absorption of rainfall by the soil in retarding the run-ff of heavy showers until the water can be absorbed, as the air is radually expelled from the soil; (4) to act as a mulch and lessen the vaporation of soil moisture.

On coarse, deep sands of low gradient the office of humus is at a inimum. There is no surface flow of storm water and no soil trans-ortation; evaporation of soil moisture is low both from the surface the soil and from transpiration by the xerophytic flora, and the rger part of the rainfall passes as percolation. With an increase the clay component, greater gradient, and a decrease in soil depth, umus becomes more essential in supplementing the water-absorbing id water-carrying capacity of the soil, its functions in this respect taining a maximum on heavy, shallow clays of mountain slopes. uch of the mountain area of the Potomac River basin affords such nditions; the slopes are steep and the soils are shallow, in part ams and in part clays of limestone and shale derivation.

Where the humus is thick, however, it possesses a high storage pacity. While there is some doubt in regard to the exact amount water humus is capable of holding, the quantity is relatively large. e lowest estimates by Ebermayer place it at considerably more an its own weight, and Wiley's investigations of Florida mucks ve it about the same capacity, while Wollny, as quoted by Henry,[a] ces it at about four times its weight, and Henry's laboratory periments tend to confirm Wollny's high limit. The capacity of mus must vary, however, not only with the state of decomposition, t with its origin as well, since the pore space is the final determinant its water-bearing capacity. The undecomposed litter, which covers e humus and from which humus is formed, does not exhibit the char-ters of humus toward water. It protects the humus, as humus es the underlying soil, from excessive transportation by surface ter and in addition from excessive evaporation, acting as a mulch. The accumulation of humus on forest soil depends, if it has neither en disturbed nor destroyed, on the kind of species forming the rest and to some extent on the soil, the destruction of humus pro-eding rapidly on loose, porous soils, which permit freer circulation air and afford the condition best suited for bacteriological activity, d since many species of trees, especially the white oak and chestnut, ve a wide range of soil adaptability, their capacity to accumulate mus is modified both by their rate of growth on the soil and by e oxidizing capacity of the soil on which they happen to be growing.

[a] Revue des eaux et forêts, 1904, pp. 353 et seq.

FOREST TYPES.

The forest types can be arranged in respect to their humus-forming capacity about in the following order, those forming the smallest amounts being named first and those beneath which humus and absorbent material accumulate to the greatest depth last: Pine type, chestnut oak-white oak type, chestnut type, birch-linden-red oak type, beech-maple-hemlock type, and spruce type.

PINE TYPE.

Beneath the pine the humus is not only shallow, but seldom accumulating to a greater depth than 2 inches. It is destroyed so rapidly that in the main it is barely replaced annually by the decomposition of litter. Where conditions are normal and the humus has not been destroyed or lessened, the top soil contains for a depth of 2 to 4 inches a varying amount of organic material which adds greatly to its absorptive capacity. On account of the open character of most of the pine forests and their situation, which is usually on exposed ridges, especially with southern aspects, and on crests, it is much exposed to desiccation by both insolation and wind. Such humus is largely protective. Forests of this character are situated on both sandy and clay soils. The pitch pine and table-mountain pine, with their associated trees, are on the sandiest phases. The soils are usually shallow or porous. They include members of the Dekalb and Upshur soil series. Shortleaf pine, with its associated trees, occurs on the driest aspects of loams and clays both of the limestone and of the yellow-shale and Upshur series. Jersey pine occurs on crests and more leachy phases of clays from yellow shale, as well as on many of the friable and easily eroded Cecil and Chester soils east of the Blue Ridge. Close-textured soils with low absorptive capacity probably form one-half of the pine type, the total area of which amounts to more than 600 square miles. Nearly all of this area has a highly dissected topography, many of the slopes being both long and steep, and offers, when denuded of humus, favorable opportunity for excessive erosion. Under the conditions of this type the protective value of humus is high in preventing erosion and increase of turbidity, as well as in lessening evaporation of soil moisture during the summer and autumn, to which this type of forest soil is much exposed on account of the thin and incomplete canopy of the crown of the pines and associated intolerant species.

Unfortunately, in much of this forest the humus has been badly burned and its accumulation prevented by repeated, in some places almost annual, fires. This condition exists over large areas. The summit of Tussey Mountain, a broad, flat-topped ridge, has been *badly* burned. It now forms a part of the Pennsylvania State Forest

Reserve, and it is probable that fires will hereafter be less frequent on it. The humus has also been burned from large areas on the west slope of Town Hill, the burned areas extending for several miles on both sides of the Maryland-Pennsylvania State line; from extensive areas on Sideling Hill, in both Maryland and Pennsylvania; from the Pratt woods on Tennile Creek, in Allegany County, Md.; from the broken region below Buck Valley, in the southwest corner of Fulton County, Pa., and the eastern part of Allegany County, Md.; from several long, narrow strips on the western slope of Tonoloway Ridge in both Maryland and Pennsylvania; from large areas on the lower part of Fourmile Creek, and from smaller areas on Scrub Ridge and on the west side of Tuscarora Mountain, in Fulton County, Pa. The accumulation of humus is prevented on large areas of pine forest on both slopes, but especially on the western, of Shenandoah Mountain in Virginia and West Virginia. Sandy Ridge, in Hardy County, W. Va., is frequently burned, as are smaller areas in Hardy, Hampshire, Mineral, Grant, and Pendleton counties, W. Va.; larger areas of pine forest on the western slope of the Blue Ridge in the valley of Virginia, and on the interior slope of the west ridge of Massanutten Mountain, and many smaller areas in other places. On many of the slopes with little or no humus soil transportation and erosion freely take place, especially where the soil from long exposure has entirely lost its humus content. Much of the forest has been reduced to sprout wood or scrub oak, and since the pines when fire killed do not sprout, they are gradually being eliminated. Owing to the suppression of young timber by fire the forest density on other areas is far too low to check the wind, and the soil, already too dry, is exposed to excessive evaporation. There are more than 200 square miles of the pine type on which the humus is too thin to perform its functions adequately and on which the soil has undergone evident deterioration in absorptive capacity. The results from this condition must be reflected in excessive run-off during heavy storms and in increased evaporation during the summer.

CHESTNUT OAK-WHITE OAK TYPE.

Humus beneath the chestnut oak-white oak type of forest seldom exceeds 3 inches in depth. This forest, like the pine type, is largely situated on slopes and ridges and occupies loams and clay soils on both the mountains and valleys. It is well represented east of the Blue Ridge, and west of that range it is the prevailing type on the dry phases of the valley clays, on all the thin-soiled, loamy slopes of the mountains below an elevation of 3,000 feet and above that elevation in numerous crests and ridges, especially those with southern aspects. On account of its situation on slopes, especially where on

heavier soils, as on the mountain limestones and the heavy clay phases, the protective function of its humus is import preventing erosion, and it is likewise important in promoti sorption by these close soils, as well as in preventing the ex evaporation which takes place from the clays, three or fou that from the sandy soils. This type covers more than 2,000 miles, of which about 700 square miles are clay soils, the rem being sands, loams, and clay loams, largely thin and in many extremely stony or strewn with rock bars.

The humus of this type has a small water-carrying capaci its chief function is protective. It has been reduced in th over more than one-half of the area of this forest type, a more than 300 square miles it has been destroyed and its mulation prevented. The reduction in thickness is due pasturage of sheep, occasional fires, and the desiccation in to thorough opening of the forest cover in lumbering or peeli which industries are being extensively prosecuted in the area type. Where the humus is subjected to a part or all of these orating influences simultaneously, the result is usually its c destruction. This has happened on large areas on the east Sideling Hill west of Needmore, Fulton County, Pa., where the tion is so effectual that the soil has washed badly on many steeper wooded slopes. The same conditions exist over larg on the west slope of the Blue Ridge, in Rockingham County, to a less extent in Augusta County, on the same range, whi of the foothills of Shenandoah and Great North mountains counties and in Frederick County, Va., and in Hardy and Ha counties, W. Va., have been repeatedly burned, and the forest c been so thinned that large areas of mineral soil are exposed ar ing. Injury of a less degree exists over areas of this type thr Grant, Pendleton, and Mineral counties, W. Va., Bedford and counties, Pa., and Allegany County, Md. It is worse in th settled communities and near the routes of transportation, and ally diminishes as distance from these destructive elements in Since the causes which lead to the destruction of humus are tive in their effects, the continued activity in lumbering, w inevitable fires and pasturage, is gradually enlarging the sprout wood, scrub oak, and brush land, on which there humus or none at all.

CHESTNUT TYPE.

The chestnut, with which usually red oak is associated a elevations and white oak at lower, produces a better hum either of the types already described. Its humus frequently a depth of 4 inches and is best when the chestnut is associat

red oak or beech. Chestnut requires a deep soil, preferring a loam or loamy clay or lighter soil, and for this reason on the mountains it grows in many places on benches where there has been little soil transportation and on lower slopes where transported material has accumulated. In the latter situation it is partly sheltered from wind and excessive evaporation of soil moisture, but on benches it is much exposed. Humus of the depth formed by chestnut has an appreciable water-carrying capacity and exerts a highly beneficial influence on the soil. There are more than 700 square miles of this type, nearly all of it on mountains. In very little of it has the humus been so completely destroyed as in the types already discussed, but there are large badly burned areas on which accumulation is seriously checked. Such areas occur on the Blue Ridge in many places, especially on the upper slopes in Page and the adjoining counties in Virginia; in many situations in the South Mountains, Tuscarora Mountains, and Scrub Ridge, in Adams, Franklin, and Fulton counties, Pa.; on the east face and fore knobs of the Allegheny Mountains in Grant and Pendleton counties, W. Va.; and on Savage Mountain and Backbone Ridge, in Allegany County, Md., and Somerset County, Pa. The total area on which the humus shows the effects of recent fires is more than one-third of the entire area of the chestnut type.

BIRCH-BASSWOOD-RED OAK TYPE.

The birch-basswood-red oak type often yields humus 5 inches deep. It is normally confined to hollows or northern slopes and sheltered situations, mostly at high elevations, and even on extremely shallow soils in such situations the humus frequently attains a depth of 6 inches, besides filling large and deep crevices between the rocks. Water can be wrung from such humus for several days after a rain, and it becomes dry and crumbly only during periods of long drought. Many of the birch and hemlock roots lie within the humus, and it undoubtedly furnishes some transpiration moisture to these species in spite of the low absorptive power they have in acid humus. This type covers a considerable area on the mountains of the watershed, being represented near the crests on northern slopes and in the hollows. The proportion of it increases with the altitude. It is especially well represented on the Allegheny Mountains and is least abundant east of the Blue Ridge and in the Shenandoah River valley. The total area probably amounts to less than 300 square miles. On account of the moist floor, only small and inconsiderable areas have been burned, and in these the burning was limited to the upper layers of humus. Heavy cutting in lumbering has caused deterioration of the humus in many places, and cattle have done some damage.

BEECH-HARD MAPLE-HEMLOCK TYPE.

Humus accumulates beneath the beech-hard maple-hemlock type to depths of 6 inches or more, and is of very fine quality, fine grained, and always moist. On very rocky land it is in places deep enough to fill the crevices between the large rocks and seldom becomes at all dry except on top. This type is best developed on the Allegheny Mountains at high elevations, especially above 2,000 feet, on moist slopes, and in deep hollows and in similar situations at the head of North Fork of Potomac River and on the mountains drained by Seneca Creek, Laurel Fork, and adjoining streams. Locally on very rocky soil the humus seems to be almost the only soil there is. Here and there this type is well developed on good soil, especially on limestone at high elevations, as at the head of North Fork of Potomac River. On limestone soils the humus and litter are in places a foot or more deep and the weeds and small undergrowth are extremely rank and thick. Where there has been no lumbering the forest cover is dense and there is low soil evaporation. This low evaporation is partly offset, however, by high transpiration from the deciduous trees of this type. Humus of this type has a high storage capacity. It is burned but rarely, and then the fire is usually confined to the top layers. Considerable areas have been badly burned, after lumbering, on Stony River, Difficult Creek, and Buffalo Creek, in Grant County, W. Va., in the south end of Garrett County, Md., and smaller areas elsewhere. Unless burnings are frequently repeated, which is rarely the case except where cutting in lumbering is severe, and unless brambles and such shrubs as make large amounts of dry brush become thick, the humus is replaced in a few years. This type of forest covers about 300 square miles. In 60 square miles of this area the humus is shallow on account of fires.

SPRUCE TYPE.

Humus accumulates to a depth of several inches beneath spruce forests, and in addition there is a deep moss, the lower layers of which hold a large amount of water. In the Potomac basin spruce is confined to the thinnest soiled, stoniest land at elevations above 3,000 feet. Much of the land has no soil at all, the loose stone lying on the undecomposed sandstone; in other places the soil is only a few inches deep, or, if deeper, is so coarse as to be scarcely more than gravel. There are 69 square miles of such spruce land situated on Stony River, Difficult Creek, and Buffalo Creek, in Grant County, W. Va., and on Seneca Creek, Laurel Fork, Spruce Mountain, and Tamarack Ridge, in Pendleton County, W. Va., and Highland County, Va., on the very headwaters of North Branch and North Fork of the Potomac. This is the region of heaviest rainfall in the

sin (pp. 34–40) and the region where the best humus is needed. F the total area of spruce land, 48 square miles, or considerably ore than half, has been burned either before or after lumbering, id the humus and forest soil have been entirely destroyed. The rned areas are southwest of Bismarck, at the head of Stony River, id at the head of Buffalo Creek, in Grant County, W. Va., and on pruce Mountain and along the face of the Allegheny Mountains, in ndleton County, W. Va. Most of this is burned bare or has a ant cover of blueberry and brambles, which have gradually spread. ver other areas, especially where the soil is best, birch and popple id fire cherry are colonizing and reestablishing forest conditions. he area of this burned land, however, is rapidly increasing as lumering proceeds. The absence of the absorbent humus and moss ver these thin-soiled areas, where it is most necessary, must have n appreciable influence on the movement of storm waters in the reams which drain these areas. No turbidity comes directly from is land.

While the reestablishment of normal humus conditions would doubtedly have a beneficial effect in alleviating the danger from gh floods, the division of the forest into so large a number of narw strips on the mountains, its diverse ownership, its location in ur States, and the rapid progress of lumbering assure a progressive centuation of the unfavorable conditions.

MELTING OF SNOW.

High turbidity usually accompanies the spring floods of April and ay caused by the melting of the snow on the mountains at the head the river, especially on the Allegheny Mountains. The longer e process of melting the lower is the flood crest and the lower the companying turbidity. The coniferous forests are instrumental prolonging the melting of the snow. Near Hancock, Md., at an vation of 600 feet above sea level, a 20-inch snow which fell durg March, 1906, was nine days longer in melting beneath the cover Jersey pines than on adjacent field land with the same soil, slope, d aspect. At the head of the river the spruce forest, with its more nse foliage, must exert a greater effect than Jersey pine in prolongg melting. Some difference, though much less marked, was ticed in the melting of snow in the deciduous forest of oak and in e adjoining fields. The total area of coniferous forest in the otomac basin is more than 700 square miles, and its influence ust be considerable in distributing the crest of floods from melting ow, by retarding melting in the forest land and by promoting sorption and subterranean drainage.

PROTECTIVE FORESTS.

The State of Pennsylvania, realizing the inability of private owners to supply the technical knowledge necessary to manage small forest areas in such a manner as to make them permanent earning investments, as well as the necessity of properly protecting by forests the headwaters of the large rivers of the State, has purchased extensive areas of mountain forest land within its borders. Portions of this land, lying on Tussey Mountain, Tuscarora and its associate mountains, and Jack and Green mountains, are on the Potomac watershed, although the greater portion is on the Susquehanna, which is essentially a Pennsylvania stream. The further extension of this protective forest to the south and southwest, to include the most important mountain areas in the Potomac basin in Maryland, West Virginia, and Virginia, is desirable. Where the States are unable to assume either the cost or the responsibility of acquiring and managing such large areas for the protection of interstate streams, this duty devolves on the Federal Government, whenever the States concerned grant the Government the right to acquire and hold such property. This right has already been granted by the legislatures of two of the States under consideration—Virginia and West Virginia—in connection with the establishment of the proposed Southern Appalachian Forest Reserve, and it would doubtless be extended by them to include the Potomac drainage basin. On account of the importance of the Potomac as a source of domestic water supply, an Appalachian forest-reserve system could fittingly be inaugurated by the acquisition of the important forested mountain lands in its basin, and, with the already extensive Pennsylvania system, two important watersheds of the Middle Atlantic drainage, the Susquehanna and Potomac, would be protected.

The control of the waters of the East by the Federal Government for the benefit of the people is as important as the control of those of the West for extending irrigation, and the principle which underlies the withholding of public money by not selling forest land is the same as that which underlies the acquiring of forest land by purchase for similar purposes.

One consideration in the selection of such forests on the Potomac basin should have reference to their protecting small mountain streams which can be utilized as sources of water supply for near-by towns and cities. The water from such forest-protected basins is of great purity, clearness, and softness, and its general use by the towns is desirable, not only on their own account, since it furnishes them a pure supply, but because by purifying their supply these towns are largely eliminated as sources of typhoid fever.

The limestone springs which are used by many towns are more

posed to contamination than freestone springs. The latter are
en only to local surface contamination, while many sink holes on
rms, which are the dumping places for waste, communicate with
derground streams that are in numerous places the sources of lime-
one springs. Many limestone springs are also streams which have
nk and reappeared on the surface at the spring. Numbers of such
rings are easily traceable to streams which have sunk in the Cum-
rland Valley, in the valley of Virginia, and on South Branch of the
otomac.

When the towns using springs or water from small streams which
e open to pollution, such as that used by Chambersburg, Pa., find
necessary to obtain new sources of supply, either because of inade-
uacy of their present supply or on account of its known pollution or
uestionable purity, as is the case with Leesburg, Va., no purer water
an be obtained than that from streams of forest-protected watersheds.
wo towns on the Potomac watershed in Pennsylvania are already
aking advantage of the permanent purity which the Pennsylvania
rest reserves guarantee and have made use of streams in forest
serves as sources of supply. These towns are Mercersburg, which
es Trout Run in the Tuscarora Mountains, and Waynesboro,
hich uses streams in the South Mountain Forest Reserve. The
ar-by city of Hagerstown, Md., has recently sought a purer supply
om the streams of South Mountain in Maryland, a few miles south
the streams which supply Waynesboro. There is assurance neither
permanency or purity to its supply, however, since the watershed
privately owned and the number of farms is increasing, with the
nstant danger of contamination.

Such a system of protective forests as has been suggested need not
designed to include the headwaters of all the streams in the basin,
it should, primarily at least, be planned to include all those which
w afford a water supply to towns of the basin or which by their
tuation will, in the future, be necessary as sources of water supply.
ith many of these towns the amount of the supply will be a matter
r consideration as well as the purity, and the protection of the
mus and the forest floor will be beneficial, while the regular cutting
hich would be carried on under the policy of protection forests
ould in no way jeopardize the amount or regularity of the stream
w.

EXTENSION OF THE CLEARED AREA.

While for a mountain region a large proportion of the land in the
otomac basin has been cleared, the limit has by no means been
ached. During the period between 1880 and 1890 the uninter-
pted emigration to the West checked further clearing of rough land
r small farms, and on account of the agricultural depression in the

following decade there was little incentive for further extension of the farmed area. In fact, much land was abandoned in Franklin and Bedford counties, Pa., and in Allegany and Garrett counties, Md., and some in Hardy, Hampshire, Mineral, and Grant counties, W. Va. The present feeling in the East that the West no longer offers any better opportunity for farming for the man of limited means than the East has checked emigration and given a new impetus to farming in this section. In addition to the fact that the man of small means, who twenty years ago would have gone West, is now buying a small farm at home, usually in timber which he clears, two other causes have stimulated additional clearing. (1) One of these is the release for farming purposes of recently logged timber land or recently opened coal land. Much of this land is of good quality for farming, and as rapidly as it is lumbered it is cleared and put in cultivation, or if too rough for tillage the large trees are killed by girdling, the ground is burned over to kill the brush, and the land is put in grass. The high price of sheep has made this profitable, and large areas of rough land, some of it extremely steep and thin soiled, are being sodded in this way on and along the Allegheny Mountains. Extensive areas are being opened for grass land on Laurel and Straight forks of North Fork of the Potomac, following the lumbering of hemlock and hardwoods, and for general farming on Savage River, following the lumbering of hardwoods, while over the entire basin there is at present a steady addition to the farming area of recently lumbered land. (2) The extension of fruit and especially of peach culture during the past decade has led to the clearing of a large amount of steep, sandy mountain land. Some of the largest orchard districts which have been cleared in the past few years are on the south slope of Tonoloway Ridge, in Washington and Franklin counties, Pa., where a heavy limestone soil has been selected for apple culture. Large areas on the southern slopes of Town Hill, in Allegheny County, Md., and on Patterson Creek Mountain, Knobly Mountain, North Mountain, Jersey Mountain, and the Allegheny Front, near Keyser, have been cleared for peaches. Much of this land would seem to be too steep and the slopes too long for permanent profitable cultivation. While the soil beneath an orchard is protected by a cover crop during the winter, clean culture is given during the summer, subjecting steep slopes to the erosion of heavy summer rains. It is possible that with the lessening of the profits which are now obtained and which are due to the freshness of the land and the immunity from insect pests the portion of this land which is least favorably situated will be abandoned.

Further contraction of the forest area tends to increase the already large disparity between maximum and minimum flows of the streams, with the concomitant influences on the potability of the water.

TURBIDITY IN RESERVOIRS AT WASHINGTON, D. C.

The water supply for Washington, D. C., before going to the filter eds usually passes through three settling reservoirs. From the ıtake at Great Falls it is piped to the Dalecarlia Reservoir, about ght hours being required for the journey. The water remains in the alecarlia Reservoir about one day and is then pumped to the eorgetown Reservoir. Thence it passes to the Washington Reservoir, which is located at the filtration plant, about 5 miles distant. bout two days are consumed in the passage from the Georgetown eservoir through the Washington Reservoir and through the filter eds. From these beds the water passes to a distributing reservoir. he conduits at the reservoirs are so arranged that any reservoir can e cut out of service without interrupting the flow from the other eservoirs or from the river.

The river water which enters the Dalecarlia Reservoir is usually urbid, the turbidity varying, according to the standard of the United tates Geological Survey, from 3,000 or more during periods of flood n the river to 15 or 20 after long periods of little or no rainfall on the otomac watershed above the intake. In general, it may be said that he turbidity will be in excess of 300 for about forty-three days in the ear, above 50 and less than 300 for about one hundred and twenty-hree days, and less than 50 for the remaining period. It will exceed ,000 for probably less than eighteen days. The first settling to lessen he turbidity takes place in the Dalecarlia Reservoir and removes the reater portion of the heaviest silt and a large part of the clay from the ater, but the clearness of the water when it leaves this reservoir epends largely on its initial turbidity. Further clarification by ttling, though slight compared with that which takes place in the alecarlia Reservoir, occurs in both the Georgetown and Washington servoirs. The finer material which occasions most of the turbidity ter the water leaves the Dalecarlia Reservoir settles very slowly. edimentation usually proceeds with a certain expected uniformity, a gh percentage of turbidity being eliminated from water of a high rbidity and a smaller percentage from that of a lower turbidity, ving to the slower settling of the finer particles which cause the low rbidity. The greater proportion of clarification in water of high rbidity is suggested by Mason as being due to the well-known ten-ncy of larger falling particles to drag down with them very fine par-cles, and even matter in solution. The subsiding, heavier silt drags wn not only much of the finest clay, but bacteria as well. It is portant, therefore, that the sedimentation in the Dalecarlia Reservoir be as thorough and uninterrupted as possible, since after the setting of the heavier particles the finer material which is left, having iled to be carried down by the coarse material, remains in suspension a eat while and is with difficulty eliminated from the water by furthe

sedimentation. Only a certain proportion of it is removed by filtra tion, and it follows that the lower the turbidity of the water as it goes t the filter beds the more pellucid the effluent.

At different times, but usually during the winter and spring, o account of wave action produced by wind, sedimentation in the rese voirs not only takes place very slowly and irregularly or not at al but additional turbidity is acquired by the water from the scouring (the sides or, at shallow places, the bottoms of the reservoirs, a portio of the thin coating of silt and clay that has previously been deposite being again taken up in suspension. With this increase in turbidit a portion of the recently deposited bacteria are also redistribute through the water.

The period of wind agitation of water in small lakes and reservoirs as has been pointed out by Birge, is largely limited to the winter an early spring months, after the water has become homothermous During the summer and early fall the temperature of the surface water becomes much higher than that of the water at the bottom of the reservoir, and the surface water is consequently much lighter, there being a warm, superficial stratum of water, the colder bottom stratum, and a thin stratum between them in which the temperature rapidly falls, called by Birge the thermocline.

Wind agitation of water during the summer and autumn, when the stratified condition is present, is largely confined to the lighter superficial layer, which does not readily mix with the dense layer at the bottom, and there is little churning of this bottom layer to cause added turbidity. The depth of the water, however, has some influence, the stratification being most marked and the difference in temperature and density greatest in deep water. The upper and lower layers become more uniform in thermal and physical properties with lessened depth, and the susceptibility to wind agitation during the summer increases. For this reason the deep reservoir is least disturbed by wave action.

During winter and spring, however, when the temperature of the water is about the same throughout, constant wind action, though light, from any one direction, will easily cause a complete overturning of the water in the reservoir. The thermal resistance to wind action which is offered by water is greatest in summer. In the winter it is greater in the day than at night and greater during sunny days than during cloudy weather. For this reason wind agitation is at its maximum during cloudy winter weather. The situation of Washington favors the existence of a long period in which the thermal conditions are conducive to wave action. The winter and spring period is long; there are a large number of cloudy, windy days, and on comparatively few days is the weather so cold that the reservoirs are frozen and protected against wind influences.

March, 1906, was a windy month, and, notwithstanding the low turbidity of the raw river water, except for a few periods of short duration, the turbidity of the water in the reservoirs remained higher than that in the river, exhibiting constantly the influence of wind action. The turbidity of the water in the Dalecarlia Reservoir remained so high that it was temporarily dropped from service and water from the river diverted direct into the Georgetown Reservoir; and during a short period of very high turbidity in the Georgetown Reservoir and lower turbidity in the river, March 9 and 10, the river water was pumped direct to the Washington Reservoir and thence to the filter beds. There was scarcely a day between March 13 and March 22 when the turbidity of the water in each of the reservoirs was not higher than that of the river water.

After filtration the water is passed into the distributing reservoir. Under low wind conditions water turned into this reservoir at a turbidity of 8 or 9 will become during the day slightly clearer by sedimentation, but during this period no subsequent clarification whatever took place. The following table shows the influence of the wind in raising the turbidity in each of the reservoirs for seventeen days in March:

Turbidity record of Washington water supply, March 6–22, 1906.

Day.	Turbidity of water at—				Turbidity of effluent after filtration.	Turbidity of water in the distributing reservoir.	Maximum wind velocity (miles per hour).[a]	Total wind during 24 hours (miles).	Direction of wind at time of maximum velocity.[a]
	Great Falls intake.	Dalecarlia Reservoir.	Georgetown Reservoir.	Washington Reservoir.					
6	820	250	70	35	5	.....	14	146	South.
7	180	[b] 350	110	40	5	.....	11	77	South.
8	120	[b] 250	[b] 120	45	5	.....	9	110	North.
9	110	[b] 250	[b] 120	65	5	.....	24	233	West.
10	95	[b] 350	[b] 110	80	5	.....	31	327	West.
11	130	[b] 350	[b] 100	80	.....	.....	15	154	South.
12	50	[b] 300	100	80	6	.....	26	278	Northwest.
13	35	[b] 180	90	65	7	7	12	168	Northeast.
14	26	[b] 180	70	80	8	7	11	160	Northeast.
15	20	[b] 250	55	90	9	8	21	266	Northeast.
16	65	[b] 350	45	60	9	8	18	183	Northwest.
17	40	[b] 250	50	55	9	8	24	274	Northwest.
18	28	[b] 250	45	50	.....	.....	11	138	Northwest.
19	22	[b] 180	35	53	9	8	13	141	Southeast.
20	22	[b] 180	.....	55	8	8	31	380	Northwest.
21	35	[b] 180	28	45	.....	.....	18	248	South.
22	40	[b] 180	26	35	8	8	22	302	Northwest.

[a] Wind velocity and direction taken from records of the U. S. Weather Bureau.
[b] Reservoir not in service on account of high turbidity.

During January, 1906, for a period of more than a week, the turbidity, both in the river and in the Dalecarlia Reservoir, was low, but there was a high increase in that of both the Georgetown and Washington reservoirs. The wind velocities were low, but the wind was constant, the prevailing directions being from the west and northwest. The high turbidity of the effluent after filtration is due to only a portion of the filter being in operation.

Turbidity record of Washington water supply, January 13-19, 1906.

Day.	Turbidity of water at—				Turbidity of effluent after filtration.	Maximum wind velocity (miles per hour).	Total wind during 24 hours (miles).	Direction of wind at time of maximum velocity.
	Great Falls intake.	Dalecarlia Reservoir.	Georgetown Reservoir.	Washington Reservoir.				
12	26	45	50	70	20	15	170	West.
13	35	28	55	65	20	16	248	North.
14	28	28	85	60	.....	10	122	West.
15	35	28	80	60	15	17	203	South.
16	35	35	70	60	12	28	226	Northwest.
17	30	35	60	60	10	20	183	West.
18	30	30	45	55	11	17	203	Northwest.

During the summer and autumn, when the water is stratified, even wind velocities of 15 to 25 miles an hour usually have little effect if the weather is bright and warm. A five-day period of high wind—May 6–10, 1906, during bright, warm weather—was accompanied by constant decrease in the turbidity of water in the reservoirs. A period of cloudy and rainy weather, very cool for the season, two weeks later, May 24–26, so far equalized the temperature of the water in the reservoirs that even lighter but steady winds showed an appreciable influence in preventing sedimentation, and the effluent after filtration, which normally should have shown a turbidity of 1 or less, rose to 3. The same effects, and usually to a greater degree, are apparent on windy, cloudy days, especially when cold, throughout every month in the year. The comparatively low velocity of the wind which occasionally, especially during the winter months, causes high turbidity, suggests the use of wind-breaks of heavy-foliaged, coniferous trees around the reservoirs, or at least on those sides from which the prevailing winter and spring winds blow, which are now unprotected.

To be most efficient a wind-break must begin a few feet back of the water level of the reservoir. The shelter power of a wind-break is variously estimated, but for winds of low velocity such as prevail here, even a low wind-break would lessen wind action for a considerable distance from the edge of the reservoir. The overturning of the water would require higher winds and would be less complete. *Libocedrus* or a mixture of *Libocedrus* and Norway spruce would probably be sufficiently tolerant not to become open below until 50 feet high, when they could be underplanted with a more tolerant species, or rows of young trees could be planted behind them. These species will also probably stand the warm summers and autumns of Washington, on account of the high humidity. Hemlock would be an ideal tree but for its slow growth, while the native red cedar has a desirable shape, but is too small and too intolerant.

The Dalecarlia Reservoir, where the raw water is received from the Potomac, and where the first settling of the coarsest matter in

suspension takes place, is an irregularly shaped basin with an extreme length, including the narrow arms, of more than half a mile. The depth of the water in many of the arms and over a considerable portion of the body of the reservoir, owing to settling up by the sediment which has been deposited from the water for many years, is less than 12 feet, and at the end of one of the arms it is even more shallow, the bottom sloping up from a depth of about 9 feet to the shore. This reservoir occupies a deep valley, with partly wooded hills rising more or less abruptly from the edges of the reservoir to heights of 50 to 200 feet, the summits of the hills lying from one-eighth to one-half mile distant from the reservoir. The reservoir valley is entirely open toward the south end, through which it drains into the river, and at the northwest end, where it is fed by a small stream. There are several other deep diverging gorges, two of which are sufficiently deep to hold arms of the reservoir.

The highest hills, rising more than 200 feet above the surface of the water in the reservoir, lie to the north and east, but their summits are about half a mile distant from the reservoir, and probably only the steep lower slopes, with a height not exceeding 100 feet, afford any protection to the reservoir as a wind barrier. On the south and west sides the hills are only about 65 feet above the surface of the water, and on account of the great length of the reservoir they protect less than half of it from southwesterly and westerly winds. The greater portion of the west end of the reservoir is exposed to winds which come up the open south valley. A portion of the west end of the reservoir is likewise unprotected from northerly winds, which would follow the north prong of the valley, or from northeasterly winds, which would follow the east prong of the valley.

The rebound of the wind from the steep slopes on the eastern side of the reservoir and the wind currents which follow the gorge-like valleys possibly explain the quick response of the water to winds of even low velocity. The period when this agitation is most constant and most pronounced is the season of defoliation of the hardwood timber on the surrounding slopes, when these trees are of least efficiency as a windbreak. It is pointed out by Professor Bigelow, of the Weather Bureau, that local windstorms frequently follow these narrow, gorge-like valleys, either in converging toward Potomac River or in spreading from it.

This constant wind action during the spring at the Dalecarlia Reservoir can be reduced by the construction of breakwaters, one across the northwestern arm and one across the southern arm. The tops of the breakwaters should be 20 feet wide, and a double row of evergreen trees should be planted alternately along each, which will still further decrease the amount of water surface exposed to the

full sweep of the wind, by protecting parts of the body of the reservoir from winds which come through the southern and northern gorges. Similar breakwaters could be placed across the other arms and one across the middle of the reservoir, the tops of all being planted with a double row of evergreen trees. Every contraction of the large unbroken water surface, which is now offered for wave action, as well as any diversion of the wind from the surface of the water, will be beneficial. It is desirable to have the settling which takes place in this reservoir as perfect as possible irrespective of whether the sides of the reservoir are paved or not, since the clearness with which the water leaves this reservoir in large measure controls the condition of the effluent of the filter. Undisturbed subsidence of the coarser silt is very desirable, as has been previously explained, since when this takes place much of the very fine suspended matter, including bacteria as well as the clay particles, is carried to the bottom by the silt as it descends.

The Georgetown Reservoir is situated about 200 yards north of Potomac River, on the south slope of the river hills. It is about 75 feet above the river, while to the north the hill gradually rises, within the distance of a mile, about 200 feet higher than the reservoir. It is entirely exposed to winds from the northwest and west, which come down the river gorge, and to those from the east, southeast, and south, which come up the river. On account of the gentle slope of the hills to the north the shelter afforded by them is slight. A breakwater separates the reservoir, which is nearly a third of a mile long, into two lagoons and lessens the violence of wind action, especially under high northwest winds. The southern and southeastern sides of the reservoir are formed by high banks, which have been built up and are rather steep on the outside. Except at a few points along these banks, where some additional banking to broaden the crest might be necessary, there is room around the entire reservoir for a double row of trees for a windbreak, and in places for three or more rows. Protection against wind is especially desirable on the west, northwest, and southwest sides of the reservoir, since these are the directions of the prevailing winds during winter and spring, when the water is in an unstable condition and lacks adequate thermal stratification to prevent overturning. The planting of the breakwater is also desirable.

The Washington City Reservoir is situated at the northeastern edge of the city, on an abrupt rise about 120 feet above the river and more than 2 miles distant from it. To the southwest and south the country is lower than the reservoir, and the wind has no check when coming from these directions. To the north and west nearby buildings and the gently sloping hills on which Petworth and the Soldiers' Home are situated rise much above the reservoir. The slope of

e hills, however, is so gradual that their protective value is ɔtful. The reservoir, which has a surface of about 45 acres, is ıt one-fourth mile long and crescent shaped, and since its longer ·nsion lies northwest and southeast, both the high northwesterly ls of winter and the southeasterly winds of early spring have ıecked play upon the surface. At times when the water is ratified a breakwater in the center would lessen churning from l. Its sides should be paved and its top sufficiently widened ,wo rows of trees to be planted. Windbreaks of three rows of ı should be planted on the north, west, and south sides of the ·voir. On the northeast side the filter beds are so close to the ·voir that not more than two rows can be planted.

THE EFFECT OF SOME INDUSTRIAL WASTES ON FISHES.

By M. C. MARSH.

INTRODUCTION.

At the instance of the United States Geological Survey, through which most of the samples were furnished, the experiments herein detailed were made by the United States Bureau of Fisheries for the purpose of learning the approximate concentrations at which the various industrial and other pollutions flowing into the Potomac basin are fatal to the food and game fishes of the region. The sources of the industrial wastes with which experiments were made are discussed on pages 191–246.

The species on which the observations were chiefly made are the large-mouthed black bass (*Micropterus salmoides* Lacépède) and the yellow perch (*Perca flavescens* Mitchill). These were selected as typical species of the Potomac fresh-water fishes, comparatively hardy and prolific, and valuable both as game and food. The perch were young and vigorous individuals, about 15 cm. in length, taken from the fish lakes of the Bureau of Fisheries in Washington. They were hatched naturally in Potomac River and had strayed through the screens of the ponds when small. The black bass were young fish of a length of 7 to 12 cm. and were hatched and reared in these fish lakes.

The bass and perch were brought from the lakes in small lots at short intervals and held in flowing tap water, and may be considered equal in vigor and resisting powers to normal wild fish not affected by aquarium conditions. When any material difference of temperature existed between the water from which the fish were taken and the pollution or dilution into which they were transferred the change of temperature was gradually made.

In addition to these two species a few salmon and trout fry and others were used as indicated in the discussion. The "shiner" is *Notropis hudsonius*.

The reaction of water which will support fish life must be slightly alkaline. When the water becomes even slightly acid fishes can not live in it, and in experimenting with acid pollutions the alkalinity of

the water used as a diluent of course affects the results. In all the present trials Potomac service water was used for diluting the pollutions and for the controls. Its alkalinity was determined at intervals during the winter by titration with decinormal sulphuric acid, methyl orange indicator, and varied from 46 to 52 parts per million of calcium carbonate equivalent.

METHODS.

The conditions under which foreign substances exercise an effect on fishes in the streams can not for the most part be exactly duplicated in the laboratory. A continual flow of water impregnated constantly with a known amount of the foreign matter under observation has not been practicable in these tests. The method followed consisted in making a known dilution of the pollution with Potomac tap water, introducing a small number of fish into the dilution held in open glass jars at the room temperature and leaving them until they died or until the experiment was otherwise ended.

All pollutions were tried with no aeration of the dilution save that occurring spontaneously at the surface, and many of them were in addition tried with artificial aeration by introducing at the bottom of the jar a continuous current of air broken into minute bubbles by passing it through linden plugs, as is usual in maintaining large aquaria. The volume of the diluted pollution used in a single trial was usually 10 liters, but varied from 5 to 30 liters. The fish were not fed while subjected to the trials. In the cases where a dilution failed to kill the trial was continued as long as circumstances allowed, in some instances two or three months. Controls were carefully carried and are separately discussed.

It is obvious that these laboratory conditions differ in some important particulars from those prevailing in polluted streams. In the first place, the fishes can not be subjected for very long periods to the influence of the pollution, for other causes will terminate the experiment, and thus the long-continued influence of very diluted pollutions which are not fatal for short periods are not covered. The aeration which occurs in flowing streams is greater than in standing dilutions and less than in dilutions artificially aerated as described, and aeration in many cases modifies considerably the polluting agent. The fish in jars are of course held under very unnatural conditions as to their immediate surroundings, particularly in the matter of space, but this does not complicate the matter much, since in aquaria with flowing water they may be held almost indefinitely.

Notwithstanding these differences between the experimental pollution and that naturally occurring, which obviously impair the accuracy of the results in the one case as applied to the other, it is equally obvious that information of value may be obtained and that reliable

nferences may be drawn from such experiments. Standing dilutions ithout artificial aeration, which are quickly fatal, will be likewise atal in natural waters, and standing dilutions copiously aerated, hich are uniformly fatal even after considerable time, would be prac-ically certain to kill in the same or shorter period in streams. Where naerated dilutions fail to kill during exposures which terminate fter a few days, it is not unreasonable to make some inference respect-ng the further dilution necessary to render the pollution harmless, emembering that an acclimating process will tend to offset the nfluence of the more prolonged exposure.

The temperature of the dilutions was substantially that of the ontrols.

A check jar in Potomac water was not set for every trial, but a eries of checks was started at different times covering the whole eries of pollution experiments. The results from the fish in the 10-ter samples of Potomac water are given in the accompanying table nd show that one perch and one bass will live for weeks in that amount f water standing without other than the natural surface aeration, ithout food and at a temperature between 15° and 20° C. They nay be summed up briefly, as follows:

In three trials one small bass lived an average of 72 days in 10 liters f water, and none less than 50 days. In two trials a perch lived 44 nd 46 days, respectively, in the former case nearly half the water vaporating, owing to the greater surface area. In two trials with two ass in each, one died after 55 days and the other in the same jar fter 71 days. In the other jar one died after 69 days, while the other as alive at the close of this record, on the seventy-fourth day.

In eight trials with one bass and one perch together in 10 liters both urvived an average period of 24 days. There is considerable indi-idual variation, for among these eight trials, the fish being selected y chance from presumably healthy individuals in the supply tank, n one case the bass died on the third day, while in another neither ish died until the forty-third day. Some unnoticed injury may ossibly account for the death of this bass within 3 days.

One bass 3 inches long in 5 liters of water in a McDonald hatching ar, with occasional aeration, lived 102 days, the surface area of water xposed to the air being 215 sq. cm.

In general the fish in Potomac water survived much longer than he fatal periods for fish in polluted water and fulfilled their office as ontrols for the latter.

In the few cases where the pollution trial was carried on in a vol-me less than 10 liters accompanying controls were set of which no urther statement is made. The control is implied if not expressed, nd no uncontrolled results are included in the statements of fatal oncentrations.

Each pollution or refuse matter which is customarily thrown into the waters of the Potomac or its tributaries will be described briefly, and the quantity or concentration necessary to kill stated as nearly as the experiments permit. The concentration is expressed as parts of the pollution sample in parts of the dilution. For example, "1 in 100" means 1 part of the pollution as received, plus 99 parts of water by volume or a 1 per cent solution.

The following table shows the results of experiments in 10-liter samples of Potomac water in glass jars; temperature of water, 4.5° to 8° C. at beginning, fluctuating with the room temperature, and never higher than 20° C.; area of exposed surface of water, 500 sq. cm. unless otherwise stated:

Results of experiments on fish in Potomac service water.

Date of beginning.	Number of		Length of bass (cm.).[a]	Perch lived (days).	Bass lived (days).	Remarks.
	Perch.	Bass.				
January 9		1	7.5	.....	50	
Do		1	7.5	.....	92	
Do	1	.....	.....	44	.....	967 sq. cm. water surface exposed; 43 liters evaporated.
Do	1	.....	.....	46	.....	2 liters evaporated; 4 c. c. of oxygen per liter after 18 days.
January 21	1	1	11	.....	3	Abandoned on third day.
January 31	1	1	11	11	7	
February 9		2	11	.....	55 71	
Do		2	11	.....	69 [b] 78	
Do		1	10	.....	[b] 78	
February 15	1	1	11-12	13	13	
Do	1	1	16	17	50	
Do	1	1	11-12	34	34	Perch spawned after thirty-first day.
Do	1	1	11-12	37	37	
Do	1	1	9.5	41	55	
Do	1	1	11-12	43	66	

[a] The length of the individual perch was not taken, as they were all of nearly the same size—from 12.5 to 15 cm.
[b] Alive at close of record.

PAPER AND PULP MILL WASTES.

Spruce fiber. This consists of coarse short fibers of spruce wood which do not pass through the screen that separates the finer fibers from the pulp made by grinding the logs. It was received from mills at Harpers Ferry, W. Va., in damp balls which lost about 38 per cent in weight by air drying.

One kilogram of the damp fibers in 28 liters of tap water failed to kill or apparently harm black bass during 10 days. During the first 4 days the fibers were held in a cheese-cloth bag, and during the remainder of the time they were free in the water without causing any mechanical injury, though the fish were annoyed when the fibers were occasionally distributed by stirring. The bass were about 6 inches in length, and the water was constantly aerated.

Spruce strips or shavings, partly bark.—These are sliverings from the outer portion of the log and include both wood and bark.

Two hundred and fifty grams of the shavings, in 28 liters of water, ith continuous aeration, was fatal to bass within 24 hours. Fifty ams was not fatal during 7 days, though the solution became very rk brown. A small constant flow of water prevents any fatal fect. Three hundred c. c. per minute passing through 2 kilograms the shavings held in a 30-liter jar failed to kill bass during 7 days, ie brown tinge of extracted bark disappearing from the effluent ter the first day.

Spruce bark.—One hundred grams of the bark stripped or cut from ie above-mentioned shavings, in 28 liters of water, with aeration, illed bass within 19 hours. Fifty grams failed to kill during 3 days. he woody portion of the shavings without the bark has no effect.

Poplar chips and dust.—When logs are prepared for digesting to ılp by cutting instead of grinding, the product of the cutter is reened. That which passes the screen is the dust referred to and ie larger pieces the chips. The two portions differ only in the size the pieces, the dust consisting of particles larger than coarse saw-ıst, while the chips are much larger. This material was from the ill at Luke, Md.

The aqueous extract from both chips and dust is fatal, the latter ore rapidly so, since it extracts more readily. One kilogram of the ıips, free and floating in 28 liters of water, with aeration, killed 10 ıinnat salmon fry within 17 hours, the solution being colored ightly brown. Five hundred grams killed 2 out of 10 fry within 22 ɔurs, 8 within 30 hours, and all within 50 hours. Three hundred ams of the dust, wrapped in cheese cloth, killed 10 fry within 22 ɔurs, the water taking on a brown tinge within one-half hour. One ındred grams killed 10 fry between the third and fourth days.

Five hundred grams of the chips were placed in 28 liters, with aera-on, and 1 mummichog, 1 sunfish, 1 goldfish, and 1 shiner were intro-ıced. Four days later 1 kilogram of chips was added, but after 10 ays all were alive. Three hundred grams of dust, wrapped in cheese oth, were placed in 28 liters, with aeration, and 1 each of the species ımed added. They soon showed symptoms of being affected, but id not succumb, and on the fourth day 500 grams of dust were lded. On the seventh day the mummichog and shiner were dead, ıt after 10 days no more deaths had occurred.

The action of fish in poplar-wood extract was unusual and seemed ɔ be characteristic. They came to the surface when its effects began ɔ be felt, but not for lack of oxygen, since the water was constantly ɛrated. Later they swam about in a slanting position, and the sal-ıon fry assumed the perpendicular, some of them whirling slowly or ıpidly on a vertical axis before succumbing.

Sulphite liquor.[a]—This is the spent liquor from the digesters in paper-pulp manufacture by the sulphite process, and is a dark-brown liquid of peculiar odor, markedly acid in reaction, and of 1.028 specific gravity at 11° C. It is a complex of imperfectly known substances designated technically as "sulphonated lignone bisulphite compounds," and is a waste of considerable importance occurring in large amounts in some regions. These samples were from the West Virginia Pulp and Paper Company, Covington, Va. The following table gives the results in detail:

Effect of sulphite liquor on perch, bass, and brook-trout fry.

[10-liter dilutions for perch and bass; 1 to 3 liters for trout fry. Perch and bass trials with 1 individual of each species.]

Dilution.	Time (hours) required to kill—		
	Perch.	Bass.	Brook-trout fry.
Without aeration:			
1 in 10		2½	
1 in 20		4½	
1 in 30			22 (all of 12).
1 in 40			22–41 (all of 12).
1 in 50			48 (9 of 12).
1 in 60	76	47	
1 in 70	70	43	
1 in 75			113 (10 of 12).
1 in 80	46	46	
1 in 100	52	[a] 17	
1 in 120	46	29	
1 in 140	70	70	
1 in 150		[a] 18	
1 in 170		89	
1 in 200		48	
1 in 200 (second trial)		[a] 10	
With aeration:			
1 in 50	(b)	(b)	

[a] Days. [b] Not killed in 27 days.

The marked irregularity in the reaction of the fishes to the sulphite liquor is presumably due to their individual variation. Even with the rather extended series of trials the dilution which is certainly harmless to bass and perch can not be stated, but may be inferred to be slightly weaker than 1 in 200. Brook-trout fry in the sac stage are more resistant to the sulphite than either bass or perch. Aeration of the dilutions lessens their toxicity very markedly, 1 in 50 with continuous artificial aeration failing to kill either bass or perch during 27 days, when the trial was abandoned. It has, in fact, been suggested that the harmful effects of sulphite pollution in streams were due to the abstraction of dissolved oxygen from the water by the oxidizable sulphite and the consequent suffocation of fishes. Determinations of the oxygen on sulphite dilutions protected from the air appear to show that no loss of dissolved oxygen sufficient to account for the death of fishes occurs. A long, narrow-necked flask, holding about 1,300 c. c., was filled to the brim with a 1 in 100 sulphite dilution at 3°

[a] One sample of this was furnished by Dr. E. C. Levy, director of the laboratory of the city water department, Richmond, Va.

C. (tap water) and kept for 23 hours at 14° C. The dissolved gases were then boiled off and 6.5 c. c. of oxygen per liter were found, which is not much short of air saturation. Since there was a slight exposure to the atmosphere the experiment was repeated, using a 1 in 25 dilution at 14.5° completely sealed and held for 19 hours, at the end of which period its temperature was 18° C. and it contained 4 c. c. of oxygen per liter. A 1 in 25 dilution causes the death of all ordinary fishes in a few hours, but this could not occur from suffocation in water thus oxygenated.

Bleach sludge.—A clear, colorless, strongly alkaline liquid of 1.006 specific gravity at 9° C. and containing a heavy white sediment. The clear liquor alone was used. Chloride of lime is the basis of the bleaching liquor. This waste comes from paper-pulp manufacture by the soda-lime process.

In unaerated dilutions 1 in 300 killed perch within 23 hours, and 1 in 400 on the ninth day; 1 in 500 was abandoned as not fatal after 14 days. In aerated dilutions 1 in 300 killed perch in 20 to 44 hours and 1 in 400 was not fatal during 5 days. Aeration does not materially affect the toxicity.

TANNERY WASTES.

"*Sour bark liquor.*"[a]—A dark-colored acid waste containing small amounts of tannic acid from the aqueous extraction of oak bark; specific gravity 1.005 at 17° C.

In unaerated dilutions 1 in 2 killed sunfish in 30 minutes; 1 in 10 killed bass, perch, and shiners in 16 hours, 1 in 20 within 24 hours, 1 in 30 within 30 hours, and 1 in 40 within 24 hours; 1 in 50 failed to kill bass during 65 hours. 1 in 30, aerated, failed to kill bass and shiners during 47 hours. The dilutions darken in color very rapidly with aeration and more slowly when standing without artificial aeration.

"*Rocker sour bark liquor.*"[a]—A brownish, cloudy, acid liquor labeled "valueless in tannic acid;" specific gravity 1.007 at 10° C.

Unaerated, 1 in 30 fatal to bass in 41 to 68 hours; 1 in 60 failed to kill bass during 9 days, but was fatal to perch in 20 hours; 1 in 100 killed perch in 22 hours, 1 in 120 in 3 days, and 1 in 140 failed to kill perch in 4 days. Aerated, 1 in 20 fatal to bass in 18 hours; 1 in 30 not fatal during 6 days, but killed perch in 16 hours; 1 in 40 killed perch in 17 hours. Perch are much more susceptible to this liquor than bass. Like the other bark liquors, the dilutions grow very dark by exposure to air.

"*Dye-house liquor.*"[a]—A greenish liquid with some dark sediment about neutral in reaction; specific gravity 1.003 at 16° C.; without pronounced taste. Dilutions have a yellow color and the undiluted

[a] From tannery of W. D. Byron & Sons, Williamsport, Md.

liquor tinges the stock bottle a yellow color, which does not readily wash out.

Undiluted and unaerated, bass are killed in 1½ hours. Unaerated, 1 in 2 was fatal to bass and perch in 19 hours; 1 in 5 to bass in 24 hours; 1 in 6 to perch and bass in 43 hours; 1 in 8 to bass in 20 hours, to perch in 23 to 42 hours; 1 in 10 to bass in 11 days, but failed to kill perch in 12 days; 1 in 15 failed to kill perch in 31 days, but killed bass in 9 days. The fish killed by the stronger dilutions were dyed yellow in color.

"*Bate.*"[a]—A straw-colored liquor; specific gravity 1.004 at 9° C.; alkalinity 400 parts per million (Ca CO_3 equivalent); contains caustic lime.

The undiluted liquor killed a bass in 20 minutes. Unaerated, 1 in 5 killed bass in 16 hours, 1 in 6 in 4 days; 1 in 7 and 1 in 10 failed to kill during 4 days.

"*Soak liquor*" *from hides.*[b]—A colorless neutral liquid, of 1.002 specific gravity. It contains merely small amounts of sodium chloride soaked from the hides preserved in salt and appears to be harmless, the aerated undiluted liquor failing to affect bass during 4 days.

A sample of only 1 liter from Cumberland, Md., labeled "sample from soaks" is apparently of a similar nature, but was too small for extended trials. Undiluted and aerated, a bass was killed within 18 hours, but the fish was anemic and unhealthy at the beginning. A perch died in a 1 in 3 aerated dilution after 15 days, but since this fish had survived previous experiments with other pollutions, and the dilution was less than 3 liters in volume, the result tends rather to show that the soak has no toxic properties.

Bass changed directly from fresh Potomac water into a solution of common commercial salt of 1.025 specific gravity, which is approximately the density of sea water, are killed within a few minutes. Bass were killed in less than 16 hours, perch within 42 hours, by transfer from fresh water to a 1.015 solution. The change from fresh water to a 1.010 solution failed to kill either during 14 days.

"*Sour liquor tail handler.*"—An acid liquor of pinkish color and foul odor, extracted originally from hemlock bark; specific gravity, 1.013.

Unaerated, 1 in 15 killed bass in 4 hours; 1 in 20 in 6 hours; 1 in 30 bass, perch, and mummichogs in 18 hours; sunfish in 24 hours; 1 in 40 killed bass and perch in 17 hours; 1 in 50 killed bass in 24 hours, perch in 29 hours; 1 in 60 killed bass in 29 hours and failed to kill perch in 54 hours. Aerated, 1 in 10 killed a shiner in 30 minutes, bass in 2 hours; 1 in 30 killed a mummichog in 41 hours, perch in 19 hours; 1 in 35 and 1 in 40 killed perch and bass in 17 hours; 1 in 50 failed to kill perch and bass during 5 days. The dilutions

[a] From tannery of W. D. Byron & Sons, Williamsport, Md.

[b] From tannery of Hambleton Leather Company, Hambleton, W. Va.

e darkened by exposure to air, this taking place more rapidly when ey are artificially aerated, which turns them grayish black.

"*Lime liquor.*"[a]—A small sample of liquor showing caustic lime kalinity.

Unaerated, 1 in 20 killed perch in 5½ hours, while 1 in 50 was not tal during a trial of 30 days.

"*Sample from hair washer.*"[a]—A cloudy grayish liquid, of 1.004 spe- fic gravity at 14° C., and alkalinity 630 parts per million.

Unaerated, 1 in 10 killed perch in less than 17 hours, 1 in 20 in ss than 23 hours, and 1 in 50 failed to kill during 13 days.

Lime and sodium sulphide.[b]—A dirty-yellowish, strongly alkaline ,000 parts per million) liquor, specific gravity 1.015 at 7° C.

Unaerated, with bass, 1 in 5 fatal in 30 minutes, 1 in 120 in 70 ours, 1 in 150 failed to kill during 43 days, 1 in 180 fatal in 90 hours; ith perch, 1 in 10 fatal in less than 20 hours, 1 in 40 in 19 hours, in 100 in 21 hours, 1 in 160 in 20 hours, 1 in 180 not fatal during days, and 1 in 200 not fatal during 44 days. Aerated, 1 in 100 illed perch in 17 hours, 1 in 150 killed perch in one case in 24 hours, another only after 8 days. Brook-trout fry in the sac stage are ore resistant than either perch or bass. With unaerated dilutions liter in volume, at 10° C., 1 in 40 killed all of 12 fry in less than 17 urs, 1 in 50 killed 9 of 15 in 40 hours, and 1 in 80 killed 7 of 12 in hours.

This liquor is the most toxic of all the tannery pollutions examined.

DYE WASTES FROM KNITTING MILLS.[c]

Spent chrome liquor.—A brownish, transparent, strongly acid liquor, 1.005 specific gravity at 10° C.

Undiluted, the liquor killed bass in 1 hour. Unaerated, 1 in 10 lled bass in 3 hours, 1 in 20 in 20 hours, 1 in 30 in 16 hours, 1 in 40 45 hours, 1 in 50 in 44 hours, 1 in 60 not fatal in 45 hours; 1 in 30 tal to perch in 24 hours, and 1 in 50 not fatal during 4 days. Aer- ed, 1 in 30 killed bass in 25 hours, 1 in 40 in 43 hours, 1 in 50 in days, 1 in 60 in 43 hours, 1 in 70 in 48 hours; 1 in 30 and 1 in 60 iled to kill perch in 14 days.

This liquor acts as a coagulant of the turbidity in Potomac water.

Spent dye liquor.—A brownish, nearly neutral liquid, specific gravity 010 at 10° C.

The undiluted and unaerated liquor was fatal to bass in 3 hours. naerated, 1 in 2 was fatal to bass in 20 hours, 1 in 5 in 17 hours, in 7 in 3 days, and 1 in 10 only after 88 days. The bass in 1 in 10 ceived no food and its death was no doubt hastened by starvation.

[a] From tannery of United States Leather Company, Cumberland, Md.
[b] From J. R. Coyer & Sons, Elkton, Md.
[c] From mill of Blue Ridge Knitting Company, Hagerstown, Md.

This dilution, though of a marked brownish-yellow color, is probably entirely harmless, and the result may be regarded as a control. Unaerated, 1 in 8.5 failed to kill perch during 8 days.

SEWAGE.

Sewage from human habitations is fatal to fishes on account of the exhaustion of the dissolved oxygen caused by the luxuriant growth of aerobic bacteria. Ten liters from the Seventeenth street canal in Washington killed bass and perch in less than 17 hours when the sewage was not aerated. Another portion aerated artificially failed to kill during the 53 hours in which the fish were kept under observation. A sample from the James Creek canal, unaerated, killed perch and bass at the end of 16 hours. With aeration no deaths or distress occurred during 48 hours. In the unaerated samples the fish give evidence of suffocation, leaping about spasmodically and then sinking weakly to the bottom as if exhausted. Oxygen determinations after the death of the fish showed about 1 c. c. per liter, and a sample in which no fishes had been held contained scarcely more.

WASTES FROM MANUFACTURE OF ILLUMINATING GAS.

Illuminating gas is itself markedly fatal to fishes. Gas from the service pipes was allowed to bubble into 20 liters of tap water near the surface for 3 to 4 minutes, and the resulting solution killed a perch within 20 hours.

WASTES FROM THE WATER-GAS PROCESS.

Filter effluent.- A cloudy grayish liquid with a moderate odor of gas; specific gravity 1.00 at 24° C. This is the effluent from filter beds which remove the tarry oils at the plant of the Washington Gas Light Company.

Undiluted and unaerated, it was fatal to bass within 6 minutes. Unaerated, 1 in 10 killed bass in 22 hours, 1 in 20 killed perch in 68 hours, 1 in 30 failed to kill perch during 32 days, and in 1 in 50 a perch spawned after 24 days and died the next day. Control perch usually died after spawning.

Tar from wells.—This sample consisted of two parts, a floating black tarry liquor and a grayish watery liquid beneath.

The lighter liquid, which floats diluted 1 in 1,000, unaerated, killed a perch in a few minutes, and 1 in 100,000 caused evident distress within 9 hours, but did not kill until the fifth day.

The heavier grayish liquid, diluted to 1 in 40, unaerated, was fatal to perch within a few hours, while 1 in 80 failed to kill during 34 days and 1 in 100 had no effect during a trial of 21 days.

Tarry liquor.—A black, tarry, strongly aromatic liquor, lighter than water; specific gravity 0.95 at 21° C. It has the highest toxicity

of all the wastes of whatever nature with which experiments were made. It does not visibly mix with water, but spreads out in a film on the surface. The dilutions were made by volume, as in other cases, though evidently only a small portion of the liquor attains solution in the water.

Eight solutions stronger than 1 in 100,000 were first tried, but all were fatal in a few minutes or hours. Unaerated, 20 liters of 1 in 100,000 killed perch in 102 to 117 hours; 1 in 200,000, in 100 to 115 hours; 1 in 300,000, in 52 to 67 hours, and 1 in 400,000 killed a perch in 12 days, but failed to kill bass during 41 days. A solution of 1 in 500,000 was made up by weighing off 40 milligrams of the liquor in a watch glass and placing it with the glass in 20 liters of water. Two perch lived in this for 24 days, when one spawned and both died the next day. The weather had become warm and the temperature of the dilution reached 19° C. A dilution of 1 in 500,000 may be considered practically harmless to perch and bass.

Aeration reduces markedly the poisonous effect. Aerated, 1 in 60,000 killed one perch in 24 hours, another after 3 days; 1 in 80,000 failed to kill during 11 days, and 1 in 100,000 during 9 days.

The sealing of the water from contact with the air, by means of the surface film, may possibly contribute slightly to the harmful effects in the higher dilutions not artificially aerated. That the substance is tremendously poisonous, however, is evident from the fact that even dilutions as weak as 1 in 40,000 kill in a very few hours, long before the exhaustion of oxygen could play a part. Moreover, the symptoms at death are manifestly not those of suffocation. Nearly all the fishes dying from gas wastes in the higher dilutions display characteristic movements. There is a rapid nervous fluttering of the fins, particularly the pectorals, with rapid respiration, and the body may assume the perpendicular. They sometimes appear to be dying for days before they finally succumb.

WASTES FROM THE COAL-GAS PROCESS.

Tar from wells.—This is ordinary coal tar, a thick black liquid with the typical odor. When dropped into water, the main portion of the drop sinks, while a lesser part separates and spreads gradually into a surface film.

The dilutions were not made volumetrically. The amount desired was weighed in drops on a strip of bristol board and then smeared in a thin layer and the strip placed in the measured quantity of water, which was stirred thoroughly. Only unaerated dilutions were used. One of 1 to 4,000 (5 grams of tar in 20 liters of water) was fatal to perch within less than 19 hours, 1 to 66,666 was fatal to both bass and perch in 4 days, and 1 to 200,000 failed to kill perch during a trial of 34 days.

Ammoniacal liquor.[a]—A nearly clear pink liquid of marked ammoniacal odor, specific gravity 1.029 at 14° C.

Unaerated, 1 in 100 killed perch in 5 minutes; 1 in 1,000, in 40 minutes; 1 in 2,000, in less than 18 hours, and 1 in 3,000 failed to kill during 24 days.

Effluent from ammonia sludge bed.[b]—A clear watery liquid with no very marked odor, specific gravity about 1.00 at 12° C.

Undiluted and unaerated, the effluent killed bass in 18 minutes. Unaerated, 1 in 10 killed perch in 20 hours, and 1 in 100 was not fatal during 34 days.

WASTES FROM BOTH WATER AND COAL-GAS PROCESSES.

Lime from "purifiers."—This is a coarse gray powder consisting originally of quicklime and having a strong odor of illuminating gas. The gas is passed through large tanks of the substance in order to remove carbon dioxide.

Five grams in 10 liters of unaerated tap water caused distress to perch in a few hours and was fatal in less than 21 hours; 1 gram in 10 liters, unaerated, killed a bass within about 69 hours; 1 gram in 20 liters, unaerated, failed to kill bass during 41 days.

Calcium oxide alone is fatal to trout fry at about 18 parts per million.

Iron oxide from "purifiers."—Iron rust is used to purify the gas of sulphur compounds. Iron filings and small pieces are mixed with wet wood shavings or thin chips and allowed to rust. The material is held in large purifiers, through which the unrefined gas is passed. The sample received for the tests was of a dark-brown color, with a strong odor of gas.

Twenty grams in 10 liters of water, unaerated, killed a perch in less than 20 hours; 5 grams in 10 liters killed a perch in 29 hours; 4 grams in 20 liters was fatal to perch in 56 hours, and 2 grams in 20 liters failed to kill during 9 days.

SUMMARY.

In reviewing the effects of the various wastes of industrial processes in the Potomac watershed, it appears that a wide gap in poisonous properties exists between the liquid wastes which come from the manufacture of illuminating gas and those from all other sources. The most toxic of the latter are made harmless by the addition of a few hundred parts of water, while the tarry by-products from the gas works require hundreds of thousands parts of water before they are diluted to the point of safety.

[a] From the Clapp Ammonia Company, Washington, D. C. It comes originally from the ammonia well of the gas-manufacturing company.

[b] From works of the Clapp Ammonia Company, which recovers ammonia from the waste products of the coal process of gas manufacture.

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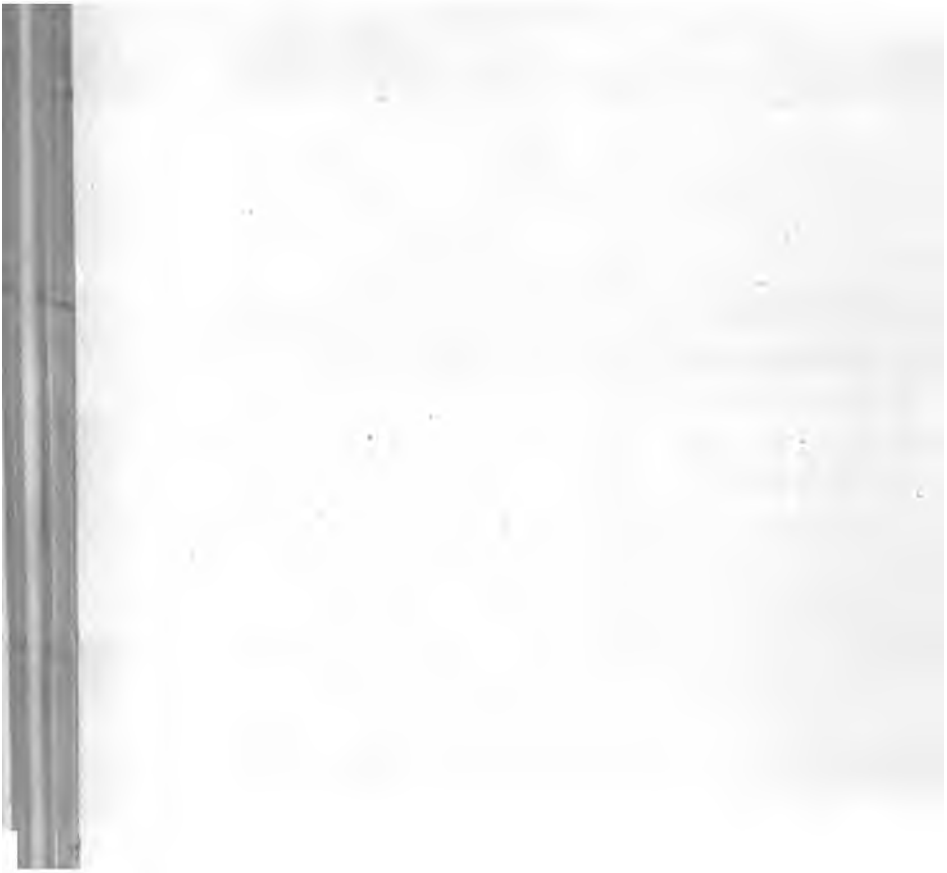

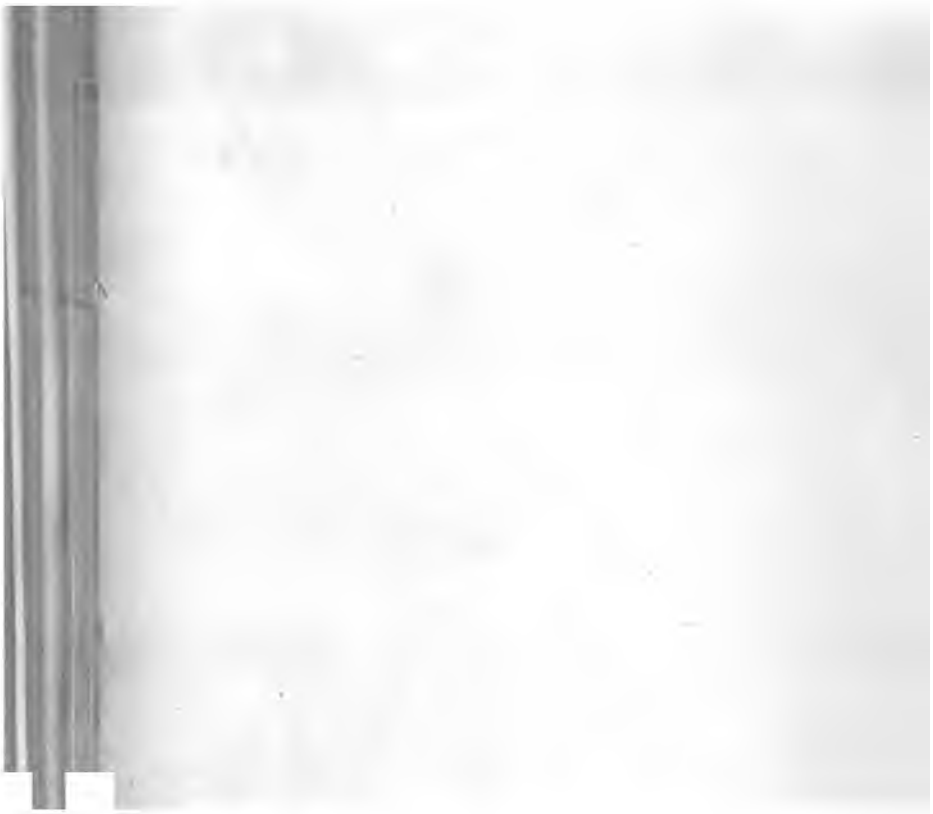

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